EVALUATING TREE SEEDLING SURVIVAL AND GROWTH IN A BOTTOMLAND OLD-FIELD SITE: IMPLICATIONS FOR ECOLOGICAL RESTORATION

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Thesis Prepared for the Degree of

MASTER OF SCIENCE

UNIVERSITY OF NORTH TEXAS

August 2007

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Boe, Brian Jeffrey, Evaluating Tree Seedling Survival and Growth in a Bottomland Old-field Site: Implications for Ecological Restoration. Master of Science (Environmental Science), August 2007, 214 pages, 36 tables, 23 figures, references, 215 titles.

In order to assess the enhancement of seedling survival and growth during drought conditions, five-hundred bare-root seedlings each of Shumard oak (*Quercus shumardii* Buckl.) and green ash (*Fraxinus pennsylvanica* Marsh.) were planted each with four soil amendments at a Wildlife Management Area in Lewisville, Texas. The treatments were a mycorrhizal inoculant, mulch fabric, and two superabsorbent gels (TerraSorb® and DRiWATER®). Survival and growth measurements were assessed periodically for two years. Research was conducted on vegetation, soil, and site history for baseline data. Both superabsorbent gels gave significant results for Shumard oak survival, and one increased green ash diameter. For overall growth, significant results were found among DRiWATER®, mycorrhizae, and mulch treatments.

ACKNOWLEDGEMENTS

Numerous persons were involved with this project and the task would have been impossible without their contributions. First and foremost, I would like to thank my committee, Dr. Ken Dickson, Dr. Ken Steigman, and Dr. Irene Klaver for their patience and guidance. Special recognition must be given to Dr. Richard Fischer of the U.S. Army Corps of Engineers Waterways Experiment Station for sponsoring the project and to Dr. Dwight Barry for assistance with setting up the project.

Thanks to Robin Buckallew for help with difficult plant identification questions and to Dr. Kevin Stevens for the use of the laboratory for extraction of the mycorrhizal spores. Dr. Kent McGregor assisted with aerial photograph interpretation. Dr. James Kennedy, Dr. Bruce Hunter, the staff of the Lewisville Aquatic Ecosystem Research Facility, the staff of BRIT (Botanical Research Institute of Texas), Richard Freiheit of LLELA, Steve Spurger, and Dorothy Thetford were all especially helpful.

The planting of the trees and the subsequent data collection was an enormous undertaking, and could not have been done without the assistance of many volunteers. Approximately sixty students of Biology 1135 Environmental Science Laboratory and Susan Maxey's class at Brookhaven College participated in this initial stage. There were additional volunteers—friends and fellow graduate students—whom I would like to thank personally, but are too numerous to list here.

Finally, I would like to thank two special people. My mother was always encouraging through my academic years. Melinda Gonzales provided inspiration and support that helped me see this project to completion

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CHAPTER 1

INTRODUCTION

Bottomland hardwood forests of the southeastern United States are among the most diverse and productive ecosystems in North America. These forests anchor soil, act as a filter of pollutants in storm runoff, and provide habitat and forage for a diverse array of wildlife species. They also represent some of the last remaining intact stretches of forest in Texas. Unfortunately, over 150 years of intensive human settlement has drastically reduced or altered these ecosystems. Harvesting of trees for lumber and clearing land for agriculture had significant impact in the early years of settlement; construction of dams and reservoirs in recent decades have both inundated large areas of forest as well as having severely altered the hydrology of the remaining floodplains.

Wet prairies and wet meadows are grasslands that are flooded or have waterlogged soils for some part of the year (Mitsch and Gosselink 2000). Soils are typically dense, clay soils that are often hydric. Wet prairies dominated by prairie cordgrass (*Spartina pectinata*) were once widespread along creeks, streams, and sloughs in the central Midwestern U.S. Fire is a major process of wet prairie ecosystems, keeping them free of woody vegetation.

The Society for Ecological Restoration (SER 2002) defines ecological restoration as “the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed.” The science and practice of ecological restoration has evolved in recent years to become an established discipline informed by many fields of expertise.   The need for restoration is great.   Frye (1986) estimated that approximately

63% of the original bottomland forest in Texas has been lost. Up to 95% of Spartina wet prairies and meadows have been transformed into agricultural fields through draining, tilling, and planting (Fraser and Kindscher 2005)

A thorough ecological restoration project is not merely revegetation of a piece of land. It involves a thoughtful process with many considerations. It must begin with serious planning and design activities. First, an analysis of the site must take place that includes an inventory of current conditions for baseline data. Climate, vegetation, soils, and hydrology are the most important factors. Also, historic conditions should be researched to the fullest extent possible to determine land-use activities that may have led to degradation. Specific problems must be identified for the objectives to be defined. Clearly stated objectives must be set. Enhancements of wildlife habitat or increasing biodiversity are examples of general goals. Specific examples may include something like establishing vegetation material that provides nesting material for wintering ducks, for example. An appropriate target ecosystem is generally defined for the project as a reference point.

In a restoration plan, performance standards must be established. If desired results are not reached in a defined period of time, corrections can be made mid-course. Lastly, a management strategy must be outlined to address the continuing needs of the site.

To carry out the actual work, key personnel must be recruited. Some tasks (e.g. herbicide application, prescribed fire, plant identification) may require trained or licensed individuals. Other work, such as the labor-intensive activities of planting trees, may involve the use of volunteers or unskilled workers. Source of stock and the timing of planting must be given careful consideration. A variety of planting methods exist; research must be done to find the most appropriate techniques. Finally, post-restoration monitoring is undertaken to assess project success and to collect information for scientific analysis.

This thesis aims to explore the issues involved in restoring a bottomland area in North Texas. Chapter 2 presents a review of the literature relevant to the issues involved in restoring this site. Chapter 3 describes a site assessment including soil testing and vegetation community survey and analysis. Chapter 4 details a project funded by the U.S. Army Corps of Engineers (USACE) to assess the performance of soil amendments on enhancing the establishment success of bare-root seedlings of two bottomland forest tree species. Chapter 5 details a suggested approach to restoring the approximately 75 acres (30 hectares) of old-field surrounding the USACE study site as well as other sites at LLELA and similar landscapes in North Texas.

Study Location

The study site is at the Lewisville Lake Environmental Learning Area (LLELA), an 1800-acre Wildlife Management Area in Lewisville, Texas. It is situated immediately south of the Lewisville Lake dam. LLELA is located at the boundary of the Cross Timbers and the Blackland Prairie ecoregions. Also, the northwestern terminus of the southern floodplain bottomland forest region falls in this region. LLELA is owned by the US Army Corps of Engineers (USACE) and is leased to an educational consortium that includes the University of North Texas and Lewisville Independent School District. The mandate of LLELA is to manage the property for preservation, restoration, environmental education, and research (LLELA 2004). The study site is located immediately south of the Waterways Experiment Station (WES) Lewisville Aquatic Ecosystem Research Facility (LAERF) and immediately northwest of Stewart Creek. Figure 1 shows the Level III Ecoregions of north Texas and the upper Trinity River. Figure 2 presents the location of LLELA in proximity to Lewisville Lake and within the urbanized area of southeast Denton County. Figure 3 shows detail of the LLELA property and the location of the site for this study.

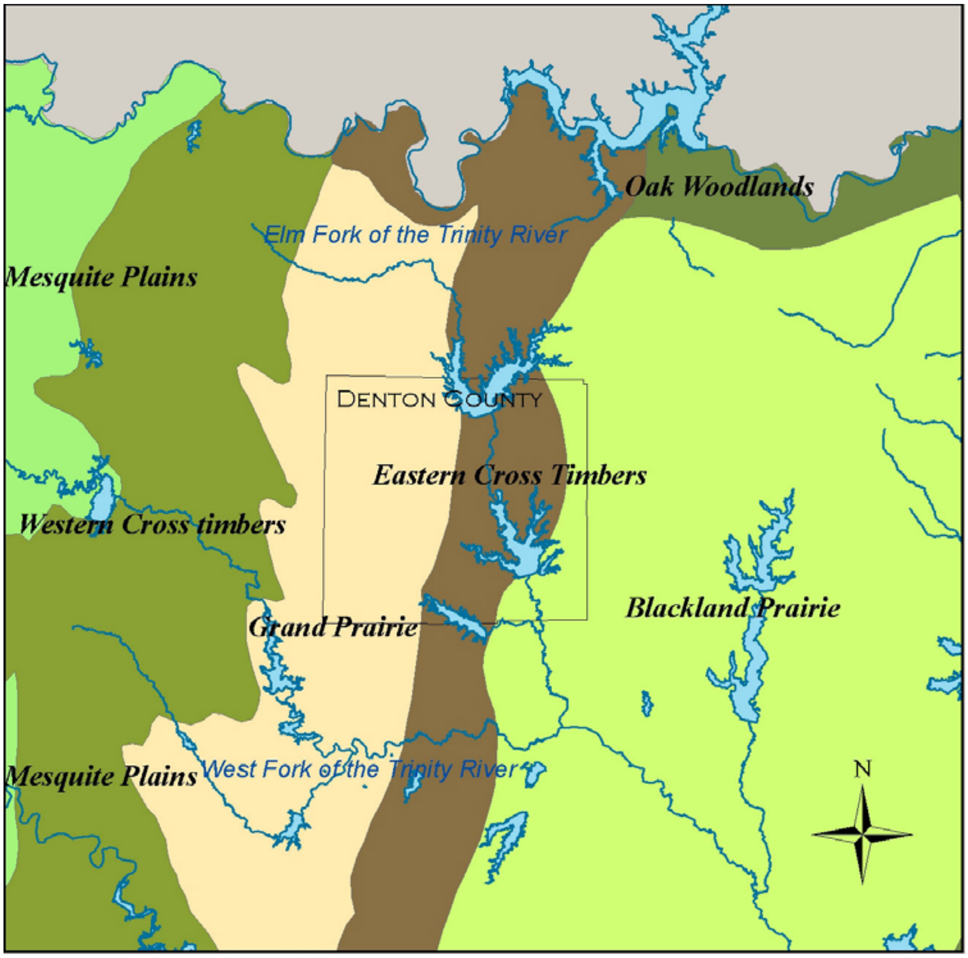


Figure 1. Map of north Texas showing Level III Ecoregions and the branches of the Trinity River in relation to Denton County. Lewisville Lake is in the southeast corner of Denton County

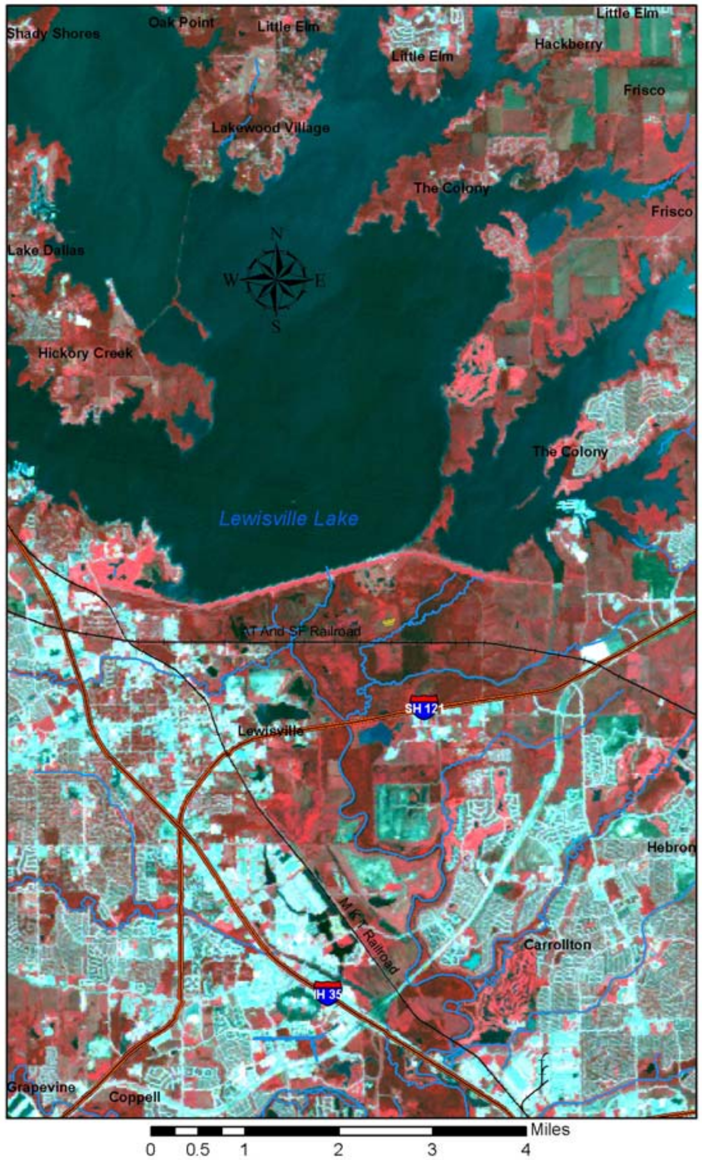


Figure 2. LANDSAT TM satellite image of southeast Denton County. LLELA is immediately south of the Lewisville Lake dam. The image is a false color image where red represents vegetation while light blue-gray represents impervious surface such as streets, driveways and rooftops

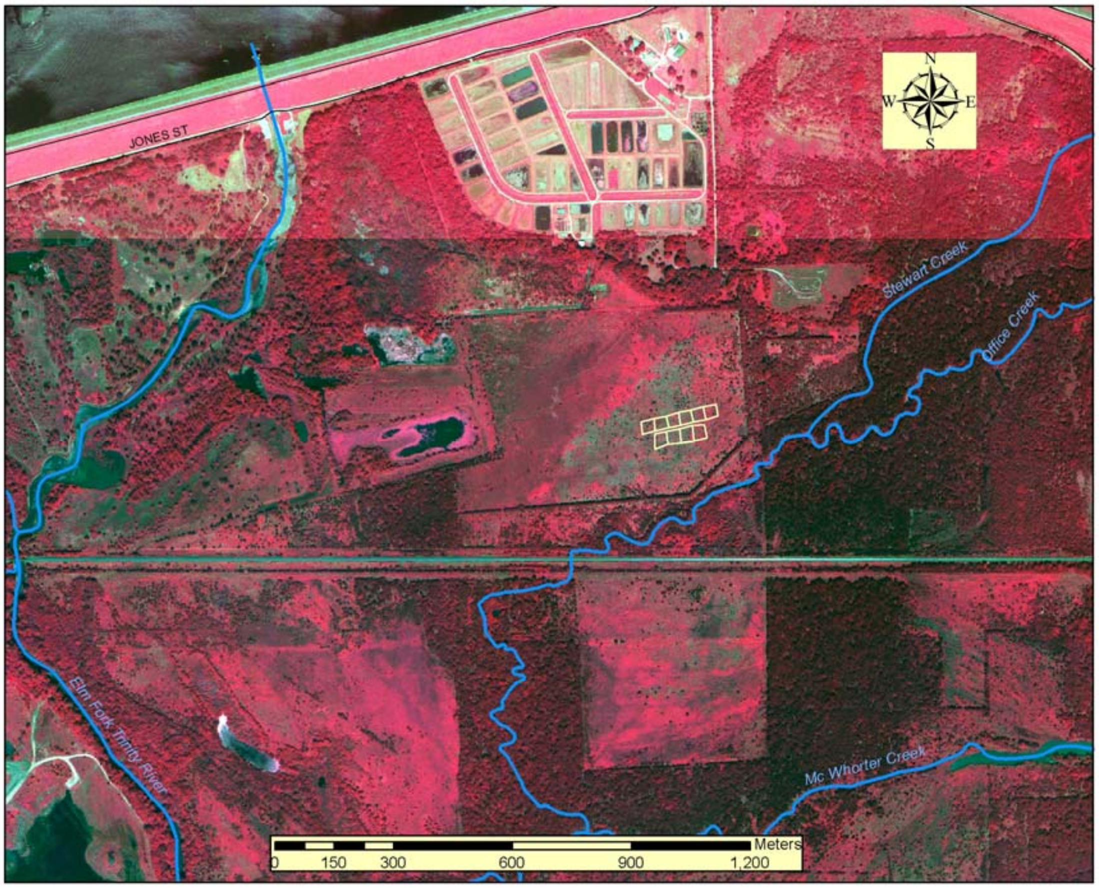


Figure 3. Detail of the central area of LLELA from a 2004 NAIP image. The yellow squares represent the location of the experimental plots. The smooth textured areas are old-fields with mostly herbaceous vegetation; the rougher textured areas are forest or woodland

Soils of the Study Site

The study site lies in the historic flood plain of the Elm Fork of the Trinity River. Riparian forest vegetation typically surrounds the river and its tributaries. According to the Denton County Soil Survey, the entire study site consists of Ovan clay soil, a fine, montmorillonitic, thermic, Udic Chromustert, that is occasionally flooded (Ford and Pauls 1980). This soil is a Vertisol, which is defined as containing at least 30% clay and exhibits remarkable shrink-swell properties as it goes through periods of wetting and drying. This action causes partial inversion of the horizons. Eventually this action results in micohighs and microlows visible on the relief of the soil surface known as *gilgai*. The Ovan series typically contains 40-55% clay. The montmorillonite clay gives the soil a high water-holding capacity as well. The solum of Ovan clays can be 1.27-2.28 meters (50-90 inches) deep.

Parent material of the soils at the study site is derived from recent (quaternary) alluvium (Ford and Pauls 1980). The Elm Fork of the Trinity River drains an area that encompasses Grand Prairie, the eastern Cross Timbers, and the Blackland Prairie. The bedrock geology of the drainage area is important to consider as the source for parent material of the soils of those regions, and consequently the parent material for the alluvial soils of the Elm Fork floodplain. All parent material is from the Cretaceous Period. The Grand Prairie is underlain by the Denton Clay, Pawpaw, Weno, and Grasyon formations, and in the western edge, the Goodland and Kiamichi Formations. The eastern Cross Timbers is underlain by the Woodbine sandstone formation. The Blackland Prairie covers the Eagle Ford Shale Formation (Hill 1887; Winton 1925). Ovan clay is rated as moderately well drained, surface runoff is slow, permeability is very slow, and available water capacity is very high (Ford and Pauls 1980). For maps of the distribution of Ovan clay soils at LLELA and in eastern Denton County, see Appendix D.

Vegetation of the Study Site

According to the Denton County Soil Survey, the characteristic vegetation type for Ovan clay is typically fifteen percent bottomland hardwood trees such as American elm and pecan, with the remaining eighty-five percent dominated by grasses such as little bluestem (*Schizachyrium scoparium*), Canada wildrye (*Elymus canadensis*), purpletop tridens (*Tridens flavus*), and Texas wintergrass (*Nasella leucotricha*) (Ford and Pauls 1980). This community description reflects the current conditions of rangeland rather than historic species composition. The ecological site description from the Soil Survey Geographic (SSURGO) database describes Ovan clay areas as Clayey Bottomland, a savanna consisting of oak (*Quercus* spp.), elm (*Ulmus* spp), hackberry (*Celtis laevigata*), and ash (*Fraxinus* spp.). The understory includes grape (*Vitis* spp.) greenbrier (*Smilax* spp.), honeysuckle (*Lonicera* spp.), and hawthorn (*Crataegus* spp.). Open areas, in addition to the grasses mentioned above, include switchgrass (*Panicum virgatum*), eastern gamma grass (*Tripsacum dactyloides*), beaked panicum (*Panicum anceps*), blood ragweed (*Ambrosia trifida*), ironweed (*Vernonia* spp.), white crownbeard (*Verbesina virginica*), and spiny aster (*Chloracantha spinosa*) (NRCS 2006). The Official Series Description from the Natural Resources Conservation Service (NRCS) National Cartography and Geospatial Center identifies the native vegetation of Ovan clay soils as hardwood forest. Cleared areas are typically in pasture or have been planted with crops such as cotton, sorghum, corn, or oats (NRCS 2005). Due to the heavy influence of agriculture and other intensive land use in the last 150 years, it is difficult to determine the true original distribution of forested versus savanna landscapes in north Texas.

By looking at the dominant trees, the specific plant association of these bottomland forest species is Society of American Foresters (SAF) Cover Type 93: *Celtis-Ulmus-Fraxinus* (sugar hackberry-American elm-green ash) (Allen and others 2001). Since the 1840's, the site most likely had some extent of bottomland forest that was cut down and converted for agricultural use, such as cattle and cotton. Perhaps it was a savanna: patches of prairie among the wooded vegetation. Today the site appears to be an agricultural old-field that is in an early-successional stage of forest development. Tree species are scattered, consisting mainly of sugar hackberry (*Celtis laevigata*), cedar elm (*Ulmus crassifolia*), green ash *(Fraxinus pennsylvanica*), with a few specimens of American elm (*Ulmus americana*), juniper (*Juniperus virginiana*), honey mesquite (*Prosopis glandulosa*), and bois d'arc (*Maclura pomifera*). Many areas are dominated by poison ivy (*Toxicodendron radicans*), and other common herbaceous species include: goldenrod (*Solidago canadensis*), giant ragweed (*Ambrosia trifida*), sumpweed (*Iva annua*), lance-leaf loosestrife (*Lythrum alatum*), heath aster (*Aster ericoides*), sunflower (*Helianthus annuus*), clasping coneflower (*Dracopis amplexicaulis*) and Johnsongrass (*Sorghum halepense*).

The land gently slopes down toward the direction of the river to the west. As the land slopes down, the soil becomes wetter and the vegetation changes. To the northwest lies a large area of solid cattail (*Typha* spp.). To the southwest there is a grove of willow trees around a small pond. The drier areas to the east feature cedar elm woodlands. Another large old-field area lies directly to the south of the study area on the other side of the railroad tracks.

The elevation of the study area ranges from 141-143 meters above sea level (462-467 feet). The elevation of the Elm Fork near the study site is 137 meters (450 feet). The study area is 1.03 kilometers from the river. Stewart Creek lies to the southeast approximately 134 meters from the edge of the site. The distance to Lewisville Lake is approximately 1 kilometer. The geographic coordinates are 33.0611° N, 96.9543° W.

Climate

Denton County lies about 402 kilometers (250 miles) north of the Gulf of Mexico. This places it at the upper edge of the Coastal Plain. The climate is mostly subhumid subtropical, bordering on humid subtropical (Larkin and Bomar 1983). The proximity to the coast indicates that during much of the year, tropical moisture-laden air masses come up from the Gulf of Mexico. Summers are typically hot, with daytime temperatures often exceeding 38 degrees Celsius (100° Fahrenheit). The prevailing winds are southerly. The area also can experience continental-type climate with extreme temperature fluctuations. Winters are generally mild, but are punctuated by events of polar air masses moving south to bring occasional cold snaps. Extremely cold polar fronts are referred to as 'blue northers'. Snowfall is uncommon. Occasional fronts that bring moisture from the Pacific arrive from the west. The average length of the frost-free period for the DFW Airport area is 249 days, with the average last frost around March 14 and the average first frost around November 17 (National Weather Service 2006).

The average annual rainfall for the Dallas-Fort Worth area over the period 1971-2000 is 34.73 inches (882.1 millimeters) (National Weather Service 2006). Except in winter, rainfall in north Texas is often accompanied by thunderstorm conditions with lightning, high winds, and occasional hail. There is no distinct dry season.

CHAPTER 2

LITERATURE REVIEW

Succession and Old-fields

Ecological succession of plant communities, specifically secondary succession, is recognized as the entire progression of species composition of a given site through time. The trajectory is directly affected by natural or anthropogenic disturbances (Morin 1999). A developed idea of succession dates back to the early twentieth century. Clements introduced the idea that a climax assemblage for a region was assigned to a plant community, referring to a stable endpoint that will develop if given ample time (Clements 1916). In this view, disturbance disrupted this process, and left the community in a state of disclimax. In addition, Clements likened a regional climax community to a superorganism, and succession is akin to the developmental stages. In contrast, Gleason (1926) developed a theory of succession that a plant species was highly individualistic, where associations were regarded as arbitrary and coincidental and the idea of a climax community was disputed (Morin 1999). Clements's ideas maintained wide acceptance for many decades; eventually Gleason's and other hypotheses gained reconsideration. Many studies and hypotheses followed, attempting first to explain the pattern and then turning to address mechanisms of ecological succession. Some important concepts include initial floristic composition (Egler 1952), resource gradeients (Drury and Nisbet 1973), patch dynamics, disturbance, steady-state, and non-equilibrium models (Morin 1999). Contemporary models are much more complex and quantitve (e.g. Markov chains) (Morin 1999). Today the topic is still hotly debated; attempts at a unifying conceptual model have been suggested, but none have gained wide acceptance.

During the mid-twentieth century, many studies looked at freshly abandoned farmland, or old-fields, as examples of successional processes (Oosting 1942; Keever 1950). This particular branch of study became known as old-field succession. These studies primarily focused on patterns or stages in vegetation composition. The general conclusion from most of these studies is that after abandonment an old-field is dominated by herbaceous annuals, then perennial grasses and forbs take over, followed by shrubs and trees. Eventually the trees mature and the canopy closes, resulting in a forest (Keever 1950; Quarterman 1957; Odum 1960; Bazzaz 1968; Bazzaz 1975; Battaglia and others 1995). But the time frame and species composition varies widely by location. In Illinois, the woody species *Diospyros virginiana*, *Juniperus virginiana*, and *Ulmus alata* appear early in succession, but establish dominance at fifteen to twenty-five years (Bazzaz 1968). An upland old-field site in Illinois was dominated by shrubs and trees at forty-plus years (Bazzaz 1968). In South Carolina, the initial stage of annuals and perennial forbs was replaced by perennial grasses in five years (Pinder 1975). In a stand in Tennesee, species like *Celtis laevigata* and *Ulmus* (*alata* and *americana*) are the first woody dominants (Quarterman 1957)

Many landmark studies were performed on the Piedmont of North Carolina. The sequence starts with crabgrass (*Digitaria sanguinalis*) the first year, horseweed (*Leptilon canadense*) and ragweed (*Ambrosia elatior*) in year two*, Aster pilosus* in year three, and broomsedge (*Andropogon viginicus*) by the fourth year (Keever 1950). A similar pattern was found in bottomlands in Indiana: annual and biennal forbs such as

Erigeron during the first year, then perennials such as *Aster ericoides*, *Solidago canadensis* in the second and third year. Some annuals were still present in subsequent years, such as *Ambrosia artemisiifolia* (Hopkins and Wilson 1974). Some species seem to be ubiquitous on old-fields, such as *Aster* spp., *Ambrosia* spp.*, and Erigeron* spp. (Keever 1983). The largest contributing families tend to be the Asteraceae and Poaceae (Hopkins and Wilson 1974).

In addition to the pattern of plant communities, researchers began to examine the physiological mechanisms behind the changes in species composition. Many traits can be attributed to early (or pioneer) and late successional plants (Bazzaz 1979). For example, early successional plants tend to have higher rates of photosysnthesis and respiration; as well, rates of photosynthesis are often higher in sun-adapted species compared to shade-adapted (Bazzaz 1979). It has also been shown that herbaceous species have higher photosynthesis rates than woody species (Bazzaz 1979). It is no surprise that most early successional species are herbaceous and sun-adapted (and shade-intolerant). Light is recognized as a major factor in species replacement, particularly in forest succession. Another example concerns the properties of propagules of early- versus late-successional species. Seeds of many early-succesional species have high viability and can survive many years in the soil (Bazzaz 1979). In contrast, the seeds of many late-succesional species, especially trees, lose viability quickly. Seeds also have variable light requirements for germination. Germination of many early successional plant seeds is enhanced by light, where late-successional species (particularly forest trees) do not require light (Bazzaz 1979). This is one way that species can be linked to disturbance. If soil is disturbed and seeds of an early-successional species are brought to the surface, germination can begin after a period of dormancy deeper in the soil. Seed germination of early-successional plants is generally epigeal, meaning cotyledons green up rapidly, photosynthesize, and grow quickly. In contrast, larger seeds (such as *Quercus*) are hypogeal, meaning the cotyledons germinate below ground and remain non-photosythetic (Bazzaz 1979).

Species composition on agricultural old-fields is largely influenced by propagule availability. Taxa with long seed dormancy (such as *Ambrosia*) may already be present in agricultural soils at abandonment. When conditions become favorable, then these species can emerge.

Method of dissemination is also important. Wind-dispersed seeds, such as *Erigeron*, *Aster*, *Andropogon*, and *Solidago*, establish themselves early in succession (Bazzaz 1979). Late-successional forest trees such as oaks (*Quercus*) and hickories (*Carya*) produce large seeds that require certain birds or mammals such as rodents for dissemination. So the plant community of an area must first be attractive to these animals in terms of cover and food before dissemination of these trees can take place (Bazzaz 1968).

Another aspect of propagule dissemination that has been studied is orientation and distance to seed source, whether carried by wind or animal. In bottomland hardwood forest areas, natural invasion of tree species in old-fields is limited to 60 meters from the forest edge (Allen 1997). Orientation of a source area to an old-field with respect to prevailing winds also affects success of invasion of bottomland tree species (Allen and others 1988).

Studies in old-fields within deciduous forest areas in Illinois revealed that plant species diversity increases with successional stage (Bazzaz 1975). Other studies contradict this and show that diversity can decrease from pioneer stages to 'climax' prairie (Perino and Risser 1972). Many other succession studies on old-fields tended to focus on plant diversity as a measure of community. But researchers such as Eugene Odum highlighted other measures such as the energy flow of the old-field ecosystem. He concluded that while the structural features of an ecosystem such as species composition and diversity change throughout time, often the functional attributes such as productivity remained in a temporary steady state (Odum 1960). He later compiled a tabular model that compares many ecosystem attributes at developmental stages (early succession) with mature stages (late succession). The traits include attributes from categories such as community energetics, community structure, life history, nutrient cycling, selection pressure, and overall homeostasis (Odum 1969).

While many physiological traits have been identified as influencing plant establishment success, many studies have also identified chemicals that may allow a plant to gain a competitive edge. Allelopathy is the production of compounds by a plant that inhibit germination or growth of another plant. The role of allelopathy in succession is debated, but many species have been shown to exude toxic compounds.

Johnsongrass (*Sorghum halepense*) is known as one of the 10 worst weeds in the world, and many studies have focused on its toxicity. Aqueous extracts of living plants and decaying residues of *S. halepense* have been shown to inhibit seedling growth and reduce seed germination of numerous species (Rice 1984). Several compounds, including *dhurrin*, have been extracted from *S. halepense* that show inhibitory activity towards root growth of several plant species as well as nine bacterial species (Nicollier and others 1985; Pope and others 1985). This suggests that *S. halepense*, and perhaps other species, may gain a competitive advantage by suppressing soil microflora that other plants may rely on for fixing nitrogen the soil (Rice 1984). Other plants shown to be alleopathic are: *Celtis laevigata*, *Solidago* spp., *Aster* spp., *Helianthus* sp., *Ambrosia* spp., and *Bromus japonicus* (Rice 1984). Many allelopathic plants are early successional species, and low species diversity on a site may partly be a result of strong dominance by alleopathic species (Bazzaz 1979).

Other factors that are identified in influencing succession and plant establishment success include nutrient and mineral availability, competition, and disturbance. Early successional plants tend to be tolerant to environmental extremes, where late-succesional species tend to be niche-specialized (Hopkins and Wilson 1974, Odum 1969). Reproductive strategy has been mentioned. Early successional plants tend to be r-selected, while late successional species are K-selected (Odum 1969). Site history is also a factor; farming practices, time of year when the field was abandoned, and the previous crop may all play a role (Bazzaz 1968; Keever 1983).

More complex descriptions of succession emerged to address the specifics that did not fit into the previous theories. Connell and Slayter (1977) proposed a three part set of interactions between species that influence succession: facilitation, tolerance, inhibition. These concepts were meant to address the overemphasis of the role of competition in previous studies (Morin 1999).

Ultimately, succession is not a simple linear process; it is the result of many complex and interacting phenomena. The idea of a climax community has fallen out of favor, and may not be relevant in light of past and future climate change scenarios. But plant communities do seem to reach relatively stable steady states for a given region based on climate and edaphic factors. As the scale of secondary succession generally spans about five hundred years, we can refer to these stable late-successional communites as old-growth to denote a unique assemblage for a site.

Bottomlands

Wetlands are a landscape feature where water plays a defining role in the biogeochemical processes of the ecosystem. They are essentially an ecotone between dry terrestrial habitats and aquatic ecosystems. The hydroperiod can vary, but is shaped by the flow of water in and out of the area, plus the geomorphology, soils, and subsurface geology. In non-tidal areas wetlands can be defined as permanent, seasonal, temporary, or intermittent, based on the duration of flooding (Mitsch and Gosselink 2000). The hydrologic budget is influenced by precipitation, surface inflows and outflows, groundwater, and evapotranspiration. Wetlands possess unique flora, fauna, and soil conditions.

Wetlands can function as sinks, sources, or transformers of energy and materials. They have a stabilizing effect on water, slowing down rapid flows that can cause erosion or flooding. Yet they can store water, lessening the effect of a drought. They have a filtering ability as well, cleansing pollutants and suspended solids from upstream waters. Primary productivity of the ecosystem can be high. Wetlands provide excellent habitat for many types of wildlife, and rare species of plants can be found there (Mitsch and Gosselink 2000).

A bottomland is a low area along rivers and streams that is periodically flooded. Bottomlands typically occur on alluvial floodplains; when forested, they are known as bottomland hardwood forest in the southeastern U.S. In the northern U.S. they are known as northern floodplain forest, and have different forest species associations. If the vegetation is herbaceous, it can be a marsh, wet prairie, or wet meadow, depending on the flood frequency and specific vegetation associations present.

Soils of wetlands are often hydric, meaning they are saturated for long enough periods that soil oxygen is reduced. These conditions result in formation of redoximorphic features such as iron oxide 'mottles' or nodules of manganese oxide (Brady and Weil 2004). Bottomland areas that are only occasionally flooded might not necessarily exhibit hydric soils, but are still considered wetlands in a broader sense.

Wet Prairies, Wet Meadows, and Sedge Meadows

Although the distinction is vague, specifically a wet meadow is a grassland habitat with saturated surface soil but without standing water most of the year (Mitsch and Gosselink 2000). A wet prairie is similar to a wet meadow, but slightly wetter. A marsh is an herbaceous wetland that is frequently or continually inundated. Marsh vegetation is specifically adapted to saturated conditions and the soils are likely hydric. Another type of herbaceous wetland is the sedge meadow, which is similar to a wet prairie, but the vegetation is primarily represented by the genera *Cyperus*, *Carex*, *Juncus, Scirpus, Eleocharis* (Galatowitsch and van der Walk 1998; Mitsch and Gosselink 2000). *Spartina pectinata*, or prairie cordgrass, is a warm-season perennial grass that often forms vast, dense, monotypic stands in wet prairies/wet meadows of the central U.S. and Canada tallgrass prairies (Mobberly 1956; Johnson and Knapp 1993). It is commonly found along streams, in sloughs, and in alluvial lowlands that are shallowly and temporarily inundated during the spring months (Fraser and Kindscher 2005). *S. pectinata* can thrive on disturbed areas, as evidenced by its abundance on highway rights-of-way and railroad embankments in the Midwestern U.S. (Mobberly 1956). The occurrence of the wet prairie community in the landscape can be viewed as part of a gradient of moisture in tallgrass prairie communities. A long-term study of the floodplains of the Missouri River in Iowa, Nebraska, Missouri, and South Dakota identifies this gradient as consisting of *S. pectinata* wet prairies and sedge meadows in the wettest areas, transitioning through areas of switchgrass (*Panicum virgatum*), Canada wild rye (*Elymus canadensis*), and eastern gamma grass (*Tripsacum dactyloides*) in intermediately moist areas, to a big bluestem (*Andropogon gerardii*) prairie on well-drained terraces and in the upland areas (Weaver 1960). Fire appears to be an influence in keeping these areas free of woody vegetation. Over 95% of the original *S. pectinata*-dominated grassland community in the United States was converted to agricultural uses following European settlement (Fraser and Kindscher 2005). Ecological restoration of these communities is desired due to its value to wildlife and the ecological services performed by wetlands. Wet prairie communities that include *Spartina pectinata* provide prime habitat for birds such as the sedge wren and the yellow rail (Fraser and Kindscher 2005).

A comprehensive approach to classify all of the unique vegetation associations of North America have been undertaken following the format of the Federal Geographic Data Committee's protocols on vegetation classification. This approach was developed and adopted by the Nature Conservancy and NatureServe and was published as the United States National Vegetation Classification System under the umbrella of the International Classification of Ecological Communities (USNVC) (Grossman and others 1998). Vegetation has been described as it appears on the landscape according to a hierarchy down to the alliance level. One level up is the association level, which is considered the diagnostic level for an ecological community. For wet meadow/wet prairie, over thirty unique vegetation associations have been named. One association, *Spartina pectinata-Eleocharis* spp.-*Carex* spp. Temporarily Flooded Herbaceous association, is found throughout the central plains of the U.S. including Kansas, Oklahoma, and Texas. Associate species found in this association include: *Ammania coccinea*, *Asclepias incarnata*, *Aster lanceolatus*, *Helianthus grosseserratus*, *Panicum virgatum*, *Paspalum leave*, *Pluchea odorata*, *Scirpus atrovirens*, and *Vernonia baldwinii* (Lauver and others 1999; Hoagland 2000; The Nature Conservancy 2004). Weaver (1960) found that *Carex festucacea* and *Eleocharis palustris* were major associates of *Spartina pectinata*.

While the USNVC only describes the vegetation as it appears on the landscape irrespective of landforms, soils or other features, these factors influence the distribution of these species and associations. In Texas, specific grassland associations have been identified in remnant prairies that follow patterns of soil clay content, organic matter, soil pH, and total annual precipitation (Diamond and Smeins 1985). Grassland communities in the northern Blackland Prairie region that have Vertisol soil typically display a *Tripsacum dactyloides-Panicum virgatum-Sorghastrum nutans* community type. This is similar to the grass association found by Weaver on the upper Missouri floodplain

(1960). Associates of this Blackland association include: *Bouteloua curtipendula*, *Carex microdonta*, *Paspalum floridanum*, *Sporobolus asper*, *Acacia hirta*, *Aster ericoides*, *Bifora americana*, *Hedyotis nigricans*, *Rudbeckia hirta*, and *Ruellia humilis* (Diamond and Smeins 1985).

While the distribution of *Spartina pectinata* is widespread across North America and once was dominant in the Midwest, its extent in north Texas before European settlement is unknown. Today it appears to be fairly uncommon, and herbarium records and botanical citations only reveal a few locations around the region. It seems reasonable to conclude that for the northern Blackland Prairie a continuum of vegetation existed that included the *Schizachyrium-Andropogon-Sorghastrum* type on upland areas (Mollisols), *Tripsacum-Panicum-Sorghastrum* association in higher terraces and drier areas of floodplain (typically Vertisols), and a *Spartina-Eleocharis-Carex* association on occasionally flooded areas of floodplain. This pattern could be a useful guide to restoration efforts in this area.

Bottomland Hardwood Forest

Before European contact, bottomland hardwood forests (BHF) once covered perhaps forty to fifty million hectares of the southern U.S. (Stanturf and others 2001). Just during the period 1883-1991, 6,500,000 hectares were lost to human activities, primarily clearing land for agriculture in the Lower Mississippi River Valley (Mitsch and Gosselink 2000). Bottomland forests are also lost to creation of reservoirs. The surface area for all of the major reservoirs on east Texas rivers (Sabine, Sulphur, Cypress, Neches, and Trinity) totals approximately 259,760 hectares (Wurbs 1986). Not all of the inundated land was BHF, but it is reasonable to say that a significant percentage was, since the areas flooded were stream and river channels and floodplain. Much of the bottomland forest in the southeast that has been spared the axe or the dam is fragmented and has lost many of its ecological functions (Mitsch and Gosselink 2000).

This highlights the great need for restoration projects. Between 1987 and 1997 approximately 35,000 hectares of BHF were replanted (Allen 1997).

The distribution and functioning of bottomland hardwood forests is primarily related to the hydrology of the stream or river nearby (Allen and others 2004). Moisture is available to plants from precipitation, groundwater, and surface runoff from streams. The moisture availability is tempered by evaporation and droughts. Flooding is a central process of bottomland ecosystems. The frequency, duration, depth, and seasonality of flooding all have a maintenance effect for the forest by providing moisture, propagules, and soil. Soil deposited by the floodwaters brings nutrients and organic matter. Flooding essentially maintains the bottomland hardwood forest ecosystem. The availability of moisture is related to stream flow patterns (Wurbs 1986). Flooding also plays a role in disturbance, with destructive effects to vegetation. The action of flood water can create mechanical damage or cause death. Flood water can also affect plant survival, growth, or vigor by length of flood period, seasonality of flood occurrence, and depth of water. Generally, floods in the dormant season are less damaging than in the growing season. And short periodic flooding is less destructive than prolonged standing water (Wurbs 1986). Plant species vary in their tolerance to submergence or soil saturation.

The physiological effects of soil flooding include reduction or elimination of soil oxygen, accumulation of CO_2, and production of compounds toxic to plants. These altered soil conditions can hinder root growth, inhibit absorption of minerals and water, and contribute to root decay (Bilan 1986). The deposition of floating woody debris can have a negative effect on living vegetation (Bendix and Hupp 2000). Flooding also has an effect on the geomorphology by erosive and depositional effects on substrate (Bendix and Hupp 2000). While destructive to individual plants, the disturbances can create gaps in the canopy that allow colonization of new specimens or species, which can lead to successional changes in the community (Bendix and Hupp 2000). As well, sediment deposits may provide new substrate for plant germination where it did not previously exist.

As stated earlier, flood tolerance varies considerably among species. In general, trees are more tolerant of flooding during the dormant season. Tolerance ratings vary by source, but some generalizations can be made. Species that are very tolerant can withstand flooded conditions through several growing seasons include Buttonbush (*Cephalanthus occidentalis*), swamp privet (*Foresteria acuminata*), green ash (*Fraxinus pennsylvanica*), deciduous holly (*Ilex decidua*), black willow (*Salix nigra*), rough-leaved dogwood (*Cornus drummondii*), and baldcypress (*Taxodium distichum*). Some of these species exhibit adaptations to flooding such as adventitious root development (Teskey and Hinckley 1977a). Moderately tolerant species can withstand flooding for at most several months during the growing season: boxelder (*Acer negundo*), cedar elm (*Ulmus crassifolia*), eastern cottonwood (*Populus deltoides*), red maple (*Acer rubrum*), persimmon (*Diospyros virginiana*), sweetgum (*Liquidambar styraciflua*), sycamore

(*Platanus occidentalis*), bur oak (*Quercus macrocarpa*), water oak (*Quercus nigra*), American elm (*Ulmus americana*), sugarberry (*Celtis laevigata*), hawthorn (*Crataegus* spp.), honey locust (*Gleditsia traicanthos*), southern red oak (*Quercus falcata*), water hickory (*Carya aquatica*). Weakly tolerant trees can only endure flooding for several days to several weeks: Shumard oak (*Quercus shumardii*), winged elm (*Ulmus alata*), mulberry (*Morus rubra*), pecan (*Carya illinonensis*), and black walnut (*Juglans nigra*). Intolerant species cannot survive even short periods of flooding or soil saturation during the growing season: flowering dogwood (*Cornus florida*), eastern redcedar (*Juniperus virginiana*), blackjack oak (*Quercus marilandica*), post oak (*Quercus stellata*), and black locust (*Robinia pseudoacacia*) (Allen and others 2001; Hosner and Boyce 1962; Teskey and Hinckley 1977b). Some species (green ash, pumpkin ash, pin oak, water tupelo) even exhibit increased growth in saturated soil than in well-aerated soil (Hosner and Boyce 1962). In general, mature trees are more tolerant to flooding than seedlings and saplings (Bilan 1986).

While surface water flows are important to the bottomland ecosystem, groundwater flow is another important component. Bottomland hardwood forests frequently sit on an alluvial aquifer associated with the nearby river or stream (Gonthier 1996).

The role of bottomland forest as wetland depends on which definition is used. According to the U.S. Fish and Wildlife system of describing wetlands, a BHF is considered to be a forested wetland class of a palustrine wetland system (Cowardin and other 1979). However, section 404 of the Clean Water Act and the ‘swampbuster’ provision of the Food Security Act of 1995 emphasize specific vegetative cover type as well as a predominance of hydric soils as indicators of 'jurisdictional' wetlands (Mitsch and Gosselink 2000). This definition may eliminate many BHF as wetlands, since they may not necessarily have hydric soils. While not a legal definition, for the purposes of this study, we will consider bottomland hardwood forest as a wetland type.

The origin of the floodplain geomorphology is a result of the processes of the river itself over hundreds of thousands or millions of years. The valley is initially formed from processes of erosion; in recent times (Quaternary Period) the floodplain soils formed from alluvial deposits left by the flooding river. Eventually terraces can form, when a stream changes course and the process of stream cutting erodes through existing floodplain. A new channel is formed, and the old floodplain becomes terrace (Brady and Weil 2002). Vegetation in floodplains can differ widely based on topography. Soil conditions such as drainage, aeration, redox potential, pH, texture, and structure, as well as flood regime can vary according to slight changes in elevation from the river (Stanturf and others 2001; Allen 1997; Robertson and others 1978). Correspondingly, the floodplain vegetation varies according to these microtopographic changes. A gradient of tree associations and corresponding elevational position has been identified (Allen and others 2001; Mitsch and Gosselink 2000). In a typical floodplain, black willow and cottonwood are found directly along the riverbank. Moving up in elevation, at a natural ridge on the first bottom one would expect to see sycamore, sweetgum, and American elm. A flat or ridge on the first bottom would feature sugarberry, American elm, and green ash. On the second terrace, species that favor a slightly more upland position will be found: white oak, hickories, and winged elm. Upland forests will seldom, if ever, be flooded.

Soils of bottomlands are formed from alluvial deposits. During flooding, coarser materials typically settle out closer to the stream while finer materials (clay) settle further out on the floodplain (Brady and Weil 2004). Generally, these bottomland soils have greater amounts of clay and organic matter, so they will exhibit greater moisture-holding capacity, productivity, and fertility (Allen and others 2001). Typically, the first bottoms are mostly clay and fine sandy loams, while the terraces have silt or sand and clay soil textures (Dickson 1986). Degree of saturation can be determined by low chroma; dark, dull soils will indicate prolonged soil saturation (Allen and others 2001).

Bottomland Hardwood Forest Types

The geographic scope of southern bottomland forest reaches from the coastal plain of Virginia, along the southern Atlantic states and Gulf Coast states to eastern Texas and up the Lower Mississisppi River Alluvial Valley to southeast Missouri and southern Illinois (Allen and others 2001). Many areas have mixed hardwood and softwoods like pine. The hardwood areas typically occupy the riparian areas and floodplains of this region. There are various attempts at characterizing the geographic pattern of vegetation distribution, some of which are being periodically revised. These include Küchler Plant Associations and Bailey's Ecoregions (which was later revised to Provinces) (Küchler 1964; Bailey 1980). Southern bottomland hardwood forest is classified by Küchler as K113—Southern Floodplain Forest. In Bailey's sysyem, Denton County falls in the 255—Prairie Parkland (Subtropical) Province, the vegetation of riverbanks and floodplains is similar to 234—Lower Mississippi Riverine Forest Province (Bailey 1980). Perhaps a more relevant scheme may be that of the Society for

American Foresters (SAF), which recognizes sixteen forest cover types that occur in the southern bottomland hardwood forest area (Eyre 1980) (see Table 1). This system recognizes dominant tree species associations, ecological relationship (flood regime, successional pattern, soils), and vegetation associates.

Table 1. Society of American Foresters southern bottomland hardwood forest cover types

Type	**SAF Number**
River birch-Sycamore	61
Silver maple-American elm	62
Cottonwood	63
Pin oak-Sweetgum	65
Willow oak-Water oak-Laurel oak	88
Live oak	89
Swamp chestnut oak-Cherrybark oak	91
Sweetgum-Willow oak	92
Sugarberry-American elm-Green ash	93
Sycamore-Sweetgum-American elm	94
Black willow	95
Overcup oak-Water hickory	96
Baldcypress	101
Baldcypress-Tupelo	102
Water tupelo-Swamp tupelo	103
Sweetbay-Swamp tupelo-Redbay	104

Based on Eyre 1980.

Some, but not all, of these associations occur in Texas. The sugarberry-American elm-green ash (SAF 93) is the most common type in the in the major river floodplain areas of the Mississippi River and the Gulf of Mexico coastal plain of Louisiana and Texas (Stanturf and others 2001). It occurs at low ridges, flats, and sloughs in first bottoms. And sometimes flats and sloughs on terraces (Allen and others 2001). Soils are typically clay or silt loam. This cover type has a long-term successional status. Major associated species include: *Acer negundo* (boxelder), *Liquidambar styraciflua* (sweetgum), *Quercus nigra* (water oak), *Quercus phellos* (willow oak), *Ulmus crassifolia* (cedar elm), *Ulmus alata* (winged elm), *Diospyros virginiana* (persimmon), *Gleditsia traicanthos* (honey locust), *Ulmus rubra* (red maple), *Platanus occidentalis* (sycamore), and *Populus deltoides* (cottonwood). Understory species include woody species such as *Cornus drummondii* (roughleaf dogwood), *Crataegus* spp. (hawthorn), and *Morus rubra* (mulberry). Understory vines are common and include *Campsis radicans* (trumpet creeper), *Parthenocissus quinquefolia* (Virginia creeper), *Vitis* spp. (grape), and *Toxicodendron radicans* (poison ivy).

Most studies of southern bottomland hardwood forests come from the Lower Mississippi River Valley, naturally because it is historically the location with the greatest extent of this forest type (Allen 1997; King and Keeland 1999; McCoy and others 2002). According to Küchler, the bottomland vegetation of the Neches, Red, Sabine, Sulphur, and Trinity Rivers of Texas are classified as Southern Floodplain Forest (Nixon 1986). Although few studies have focused specifically on this western edge of the ecoregion, it may vary somewhat it vegetation composition due to differences in rainfall, soil, etc. Notwithstanding its similarities to the southern bottomland hardwoods, the Texas bottomlands represent a distinct type (Nixon and Willett 1974). In a comprehensive study of the entire Trinity River, Nixon and Willett (1974) found nine SAF cover types in its course from the Fort Worth area to the delta east of Houston. They found that by importance value, the Upper Trinity forest vegetation is dominated by *Ulmus crassifolia*, *Fraxinus pennsylvanica*, and *Celtis laevigata* (Nixon and Willett 1974). A study of old-growth forest near Garland, Texas (in the Blackland Prairie) found similar results, with the addition of *Carya illinoinensis*, *Quercus shumardii*, and *Quercus muhlenbergii* (Nixon and others 1991).

Why is it that some bottomland areas develop into forested areas while others stay open and herbaceous? Several factors may be involved. One study in east Texas attempted to address this question by comparing a bluestem savanna, wet meadow, and forested area. The authors concluded that edaphic factors and fire history may be the main influences (Streng and Harcombe 1982). The wet meadow exhibits poorly drained soil that inhibits flood-intolerant woody species. On the bluestem prairie fuel moisture would have been lower, contributing to higher flammability.

Impoundments

Large-scale impoundment of waterways with dams has been a major endeavor since the twentieth century. Projects for flood control, water supply conservation, generation of electricity, and recreation have severely and permanently affected many streams and waterways worldwide, including Texas.

Although very few thorough studies exist, research has demonstrated several ways that dams and lakes alter the downstream ecosystem. First, the flow patterns of the river are changed. Water releases from the dam may be more even, and flood pulses are controlled. Overbank flooding may no longer occur. In general, downstream flow is reduced overall (Wurbs 1986; Johnson and others 1982). The seasonality of discharge is also altered: water releases from dams are out of sync with vernal flood pulses typical of BHF habitats (Johnson and others 1982). Peak flow is lessened and mean annual flow may be lower as well. River meandering can be practically eliminated. Scouring floods are reduced or eliminated, and sediments that build point bars often settle out in the reservoir (Johnson and others 1982; Nilsson and Berggren 2000). These sediments also carry nutrients and propagules that contribute to the forest processes (Bendix and Hupp 2000). Impoundment can also affect groundwater recharge and water table levels (Chang 1986). In some cases, ground water and soil moisture may increase in the vicinity of the reservoir and in the riparian zone (Wurbs 1986; Duke and others 2002), but other areas of the floodplain may see the available groundwater lowered (Nilsson and Berggren 2000). Water from the lake itself can seep directly into groundwater, but whether recharge is occurring depends on local geology and ground water flow systems (Winter 1983; Winter 1986). Ultimately these hydrologic changes can affect forest species composition, density, diversity, and growth in the floodplain (Chang 1986). Reduced growth of trees such as boxelder and American elm was found after impoundment of a section of the Missouri River in North Dakota (Johnson and others 1982). Essentially, when flooding is reduced a ridge or floodplain flat site begins to show characteristics like that of a terrace (Stanturf and others 2001). Earthen dams are known to seep water as well (Yost and Naney 1974). Therefore it is possible that areas nearby a dam may have increased groundwater from the reservoir, while areas of floodplain further downstream may see reduced groundwater inputs.

Regarding water tables, research concludes that they are complex and continually changing (Winter 1983). The effect of dams and reservoirs on groundwater hydrology is little understood and warrants further research.

Several studies have analyzed the groundwater near the Lewisville Lake dam on the LLELA property. Groundwater monitoring shows that the seepage from the dam feeds a wetland near the dam (Stewart and others 1998; Dodd-Williams 2004). As well, changes in the hydraulic gradient along the edges of the study area correspond to changes in the lake elevation (Stewart and others 1998). The hydraulic head values are highest at the north end of the study area, near the dam, and are lower toward the south and west edges (Stewart 1996). Distance from the dam and the configuration of the subsurface alluvial deposits determine the extent of effect of groundwater recharge from Lake Lewisville. It appears that the direction of groundwater flow is not uniform, and that the area exhibits a low hydraulic conductivity (Stewart 1998).

Superabsorbent Soil Conditioners

Synthetic polymers were developed in the 1950's for many uses, including use as soil conditioners in agriculture and soil protection projects. Initial research showed great promise in improving certain soil conditions, such as improving soil aggregation to prevent erosion (Wallace and Wallace 1986). But the early formulations were difficult to use and were too expensive for widespread use (Wallace and Wallace 1986). Subsequent advancements with the technology in the 1980's have yielded gel-forming superabsorbent polymers of several types including polyacrylamide (PAM). Various formulations of PAM can differ by charge. In particular, the anionic polyacrylamide polymers promised the greatest benefits for soil stabilization. Viscosity of PAM is increased with higher molecular weight. Typical polyacrylamide formulations for soil conditioning are water-soluble and have a high molecular weight (Seybold 1994). Also in the 1980's, cross-linked polymers emerged as a promising product. These newer polymers have increased water storage capacity and thus require much lower amounts of product to achieve desired results (Johnson and Veltkamp 1985). A wide range of benefits was demonstrated from research with these compounds.

The mode of action of the PAM polymer is attributed to its surface that acts as a semi-permeable membrane (Johnson 1984). The anionic polymer adsorbs water through a 'cation bridge' that exists between negatively-charged ions in the soil and the polymer itself (Seybold 1994). Many factors can affect the strength of these bonds: pH, type and amount of exchangeable cations, molecular weight of the polymer, and in particular the amount of clay (Seybold 1994). The effect of dissolved salts in irrigation waters on the water storage properties of PAM is discussed by Johnson (1984). The clay fraction is where much of the interaction with the polymer takes place, as it is the colloidal layer that is the seat of activity for adsorption of cations and anions in the soil (Johnson 1984; Brady and Weil 2002).

Scanning electron microscopy reveals a framework structure of expanded polymer that displays a ‘matrix of vacuoles’ for water storage that are connected by hexagonal ‘bridges’ of the cross-linked polyacrylamide (Johnson and Veltkamp 1985). This physical structure is believed to contribute to increased water-storage capacity of the cross-linked polymers by providing a barrier to the escape of water from the gel.

Very little information is available about the toxicity and environmental fate of polyacrylamide and its breakdown products. Orzolek (1993) reports some degree of microbial degradation with various formulations of hydrophilic polymers. However, PAM in the soil itself is resistant to microbial degradation, but is degraded by sunlight and mechanical breakage from cultivation (Seybold 1994). PAM itself has been demonstrated to be non-toxic to plants, fish, mammals, and humans (Seybold 1994). However, during the synthesis of PAM, residual amounts of the monomer acrylamide are inevitably produced. Acrylamide is a known neurotoxin to humans and other primates, other mammals, and fish (Seybold 1994). The acrylamide content of commercial products has been reported at levels as high as five percent, but are typically less than 0.0002 percent (Seybold 1994). Acrylamide is highly water soluble, and does not accumulate in soils. It is biodegradable and in soil at ambient temperatures has a half-life of 18 to 45 hours (Seybold 1994).

Several formulations of PAM are commercially available. TerraSorb® is one such product. It is a cross-linked potassium polyacrylamide-acrylate copolymer, which is available in a granular form. The manufacturer claims the product has an absorption capacity of approximately 200 times the dry weight in distilled water and has an effective life of up to five years. The acrylamide monomer level is reported to be less than 0.05 percent (TerraSorb® 2004).

The application of polyacrylamides affects several parameters of soil quality and plant growth: the physical structure of the soil, the ability of the soil to move or hold water, and the subsequent effects on plant seed germination, seedling growth and vigor.

Research has shown that the application of PAM had significant and long-lasting effects on lowering the bulk density of clay loam soils (Terry and Nelson 1986). Bulk density was decreased and subsequent soil compaction was lower on clay subsoil in California (Wallace and others 1986b). Soil aggregate stability was improved by application of PAM (Mitchell 1986; El-Morsy and others 1986). Soil aggregates treated with PAM were three to four times more stable than in soils that were not treated (Terry and Nelson 1986). The strength of soil aggregates can prevent the formation of soil crusts, which can hinder seedling emergence, reduce water infiltration, and lead to erosion. Application of PAM to soil maintained aggregate stability over multiple irrigation events, reduced penetrometer resistance (Cook and Nelson 1986) and stabilized the upper horizon of soil against crust formation (Mitchell 1986). Surface soil crusts that developed on flood irrigated plots had penetrometer resistance that was approximately ten times greater than on PAM-treated soils (Terry and Nelson 1986). Wallace and Wallace (1986a) demonstrated a variety of application methods of PAM that can be used toward stabilizing soil surfaces and preventing erosion.

Water is a vital component of any soil, and many factors can affect a soil's capacity to absorb surface runoff and hold stored water. Soil texture based on particle size, size and arrangement of pore space, and aggregate structure all determine a soil's ability to store and move water.

Hydraulic conductivity refers to the ability of water to move through soil in response to a particular potential gradient (Brady and Weil 2002). An aqueous solution of PAM increased hydraulic conductivity of a sandy loam Alfisol (El-Morsy and others 1991). The results suggest that this benefit is maintained through subsequent irrigations after the polymer application.

Infiltration capacity is the rate at which water enters soil pore spaces, and is also influenced by soil texture and structure. Low concentrations of PAM in solution with irrigation water improved infiltration rates for four different soil types in California (Wallace and others 1986b). This study also showed that total pore space was increased in treated soils. Water treated with anionic PAM improved water penetration of sodic soils in California (Wallace and others 1986a). On a flood-irrigated clay loam site in Utah, PAM-treated soil had infiltration rates approximately twice that of the control. Experiments on various application methods of PAM showed increased water penetration is six of the nine methods (Wallace and Wallace 1986). PAM applied in solution to a montmorillonitic silty clay increased infiltration rates during the first four hours of irrigation from 30 to 57 percent, but did not increase soil moisture storage or final infiltration rate (Mitchell 1986). As well, dry application of PAM did not produce significant results. Effectiveness varies with concentration of solution and texture of soil. High clay content, especially montmorillonite, can exhibit lower hydraulic conductivity; additionally, greater adsorption of PAM has been demonstrated for illite than for montmorillonite (Mitchell 1986; Seybold 1994).

Water loss from evaporation is a major concern for agriculture and conservation plantings, especially in arid environments. Generally, researchers concluded In the 1980's that increased availability of soil water was not due to increased water-holding capacity, but to increased water penetration (Wallace and others 1986b). However, newer formulations of polyacrylamide featured cross-linked monomers that reduced the water solubility of the gel, while improving on the water absorption and release properties of the product (Johnson and Veltkamp 1985). Improved water storage, greater pore space, increased infiltration and hydraulic conductivity can all prevent soil water loss to evaporation.

Experiments using plants have been conducted in greenhouses and in field trials that show some benefits to emergence, growth, survival, and vigor. A solution of PAM that was applied to two sodic soils increased emergence rates and dry weights of tomato seedlings (Wallace and others 1986a). Seeds of white clover, barley, and lettuce were sown into five types of PAM mixed with sand. All types improved germination and establishment of barley. With white clover, all types improved germination, and three of the types improved establishment. Lettuce seeds showed improvement in establishment for several of the treatments, but one type of PAM was inhibitory to establishment (Woodhouse and Johnson 1991). Cook and Nelson (1986) showed that alfalfa (*Medicago sativa*) and sweet corn (*Zea mays*) emerged days earlier in soils that contained PAM in solution compared to soils treated with granular PAM.

In a field experiment at LLELA (Lewisville Lake Environmental Learning Area) in north central Texas, bare root seedlings of bur oak (*Quercus macrocarpa*) and Shumard oak (*Quercus shumardii*) were planted with a water-retention polymer in a bottomland along the Trinity River (Barry and others 2004). A flood occurred which inundated the seedlings for three weeks. Naturally, no treatments were found to aid survival in this case, and the polymer may have been one cause of mortality due to the swelling action of the gel which ejected trees from their holes. The researchers concluded that too much polymer was applied to the backfill soil when the trees were planted (Barry and others 2004). In another experiment involving trees, Gilman (2004) found no significant effects for root weight, trunk diameter, and height of live oaks (*Quercus virginiana*) to which several types of PAM (including TerraSorb®) were applied to the root ball. However, Ingram and Burbage applied TerraSorb® to live oak transplants (1986). They found no effects on survival, but the polymer increased spring growth compared to other treatments.

Another type of superabsorbent product that has a very different formulation from the polymers is DRiWATER®. DRiWATER® is a patented product which consists of a gel that is 98 percent purified water and 2 percent cellulose and alum, which bind the water in the solution. The manufacturer's literature claims the process of soil bacteria degrading the gel releases water that becomes available to the plant (DRiWATER®

2003). The product itself is applied from a ‘gel pac’ that is placed into a tube that is buried with the plant or tree. A new gel pac is placed in the tube periodically throughout the growing season. The soil end of the tube is open to the root zone of the plant. The top end of the tube is capped after the product is placed in the tube. There is almost no literature that mentions use of DRiWATER® as an aid to plant cultivation or revegetation products. One small study in Nevada reports positive results with the planting of various desert plants (Newton 2001). The author claims that plant survival was comparable to hand-watering, and that the product saved a significant amount of labor. Another study on Santa Catalina Island in California found no significant effects in a planting of scrub oak (*Quercus pacifica*) seedlings (Serrill 2006). Research in the arid coastal lands of southern California has shown some positive results with DRiWATER® in plantings of *Artemisia californica* (Platter-Reiger 1999) and *Salvia mellifera* and *Malosma laurina* (Platter-Reiger 2002). Several studies by the U.S. Army Corps of Engineers in Arizona and Texas are currently underway to test the effectiveness of DRiWATER® (Fischer 2004).

Several factors appear to influence the success of superabsorbent polymers such as polyacrylamide. Method of application (in solution or dry granules), quantity of material used, soil type (particularly amount and type of clay), and soil salinity have all been shown to affect the benefits to soil and plants. Another trend in the literature regards the exact formulation used in a particular study. The specific chemical type may not be reported, and products may not be specifically mentioned by brand name. There are several chemical classes of superabsorbent polymers, and variations on formulation exist within each class. Although it can be difficult to determine what effects to expect from a particular type of superabsorbent compound, the efficacy of the cross-linked polyacrylamide polymers has been established by a body of studies.

Mycorrhizal Fungi

Mycorrhizal fungi have been receiving considerable attention in ecological studies in recent years. These are fungal species that colonize plant roots and form a mutualisic relationship. In fact, many species of plants are *obligatorily mycorrhizal*, meaning they could not survive without the fungi. Other species are *facultatively mycorrhizal*, meaning that they benefit from the relationship, but it is not required for survival. (Allen 1991). There are several types of mycorrhizal fungi; the two most common are ectomycorrhizae (EM), or sheathing mycorrhizae, and endomycorrhizae, more commonly called arbuscular mycorrhizae (AM). Some AM have vesicles (oil storage organs in the roots), and are called vesicular-arbuscular mycorrhizae (VAM). Sheathing mycorrhizae enclose the roots in a dense sheath and have limited penetration into the host cells. AM form a loose network of hyphae (fungal body filaments) on the root surface, but develop extensively within the root tissue cells (Smith and Read 1997). Most plant families host AM, with the notable exceptions of the Cruciferae, Chenopodiaceae, and Resedaceae (Allen 1991). EM are known to associate with most conifers, oaks, and willows. It is now widely accepted that 90% of all terrestrial plant species on earth form associations with mycorrhizal fungi (Perry and Amaranthus 1990). This relationship may be so important that most ecosystems may not be healthy without the proper mycorrhizal population.

This symbiotic relationship offers valuable benefits to each organism. Plants provide the fungi with carbohydrates created by photosynthesis. Plants receive a variety of benefits. Essentially, the hyphal network of fungal filaments extends the range of plant root hairs, which serves to enhance absorption of water and nutrients from the soil. Many nutrient elements (P, N, Cu, Fe, K, and Zn) are transferred by mycorrhizae (Smith and Read 1997). Research also suggests that mycorrhizae benefit plants with increased drought tolerance, resistance to disease, weed suppression, and improved soil structure (Jeffries and Dodd 1991; St. John 1998). The fungal filaments bind soil particles and produce the soil glue *glomalin*, enhancing aggregation. This in turn increases pore space and prevents wind erosion (Jeffries and Dodd 1991).

Recent research has focused on grass and forb endomycorrhizal relationships. Studies have shown that prairie species like little bluestem (*Schizachyrium scoparium*), big bluestem (*Andropogon gerardii*), Indian grass (*Sorgastrum nutans*), rough gayfeather (*Liatris aspera*), and others have mycorrhizal associations. This is significant, because as much as 65% of the biomass in a prairie is underground (Miller 1997).

In the past, the Cyperaceae were considered to be a non-mycorrhizal family. But evidence is emerging that indicates that it mycorrhizal colonization may be prevalent (Miller and others 1999; Muthukumar and others 2004). A recent survey of 221 sedge species reveals that 40% are mycorrhizal, 11% are facultatively mycorrhizal, and 49% are not mycorrhizal (Muthukumar and others 2004). For the genus Carex, 34 of 76 species are mycorrhizal, and 4 are facultatively mycorrhizal (Muthukumar and others 2004). The extent of colonization may be determined by environmental factors, principally moisture regime (Anderson and others 1986, Muthukumar and others 2004). The importance of the role of mycorrhizae on the growth and development on the Cyperaceae is still unknown.

Human activity associated with agriculture and urbanization has caused disruption of unknown magnitude of mycorrhizal communities. Biocides, plowing, topsoil removal, and erosion are major factors. Successful restoration of these sites may ultimately depend on re-establishing the mycorrhizal web of the ecosystem (St. John 2000).

Field methods for large-scale restoration are still largely in the experimental stage, but the results have been promising (Miller 1997; Bever and others 2003). The main factor in deciding whether to involve mycorrhizae in a restoration program is the degree of degradation of the site. Sites with a recent history of grading, erosion, mining, heavy pesticide or herbicide use, excavation, or severe overgrazing are good candidates for inoculation techniques, because the mycorrhizal population will be depauperate or eliminated. Presence of weedy species in the Chenopodiaceae or Brassicaceae may indicate lack of a healthy mycorrhizal population (St. John 2000). Sites with less disturbance or where sufficient time has passed to allow some native plants to return to the site may have a recovering native fungal population. In this case, it may be more appropriate to add net-building mycorrhizal host plants rather than inoculate (St. John 1998). These are plants that devote a large amount of photosynthate to the symbiotic fungus.

Mycorrhizal species are very slow growing and need a host plant, so careful distribution of the inoculum is the key to establishment success. Inoculum can be cultured or can be obtained from commercial sources. There are several methods of dispersing the inoculum:

- Adding a layer of topsoil that hosts the desired species of fungi
- Inoculating nursery stock of native plant species
- Land imprinting
- Hydroseeding
- Seed drill
- Trench method
- Pellets or seedballs that contain a mixture of fungi and native seeds

Some factors to consider:

Research shows that commercial inoculum products vary widely in quality and may be unreliable (St. John 2000). Since EM species can be cultured and stored without a host plant, those inoculant products have been used successfully for years in forestry applications.   AM species require a host, so the commercial products must have a formulation that allows for maximum survival in storage. The proper mycorrhiza type must be matched to the plant or tree species being restored. Additionally, large-scale applications of inoculum may be expensive and labor intensive. Conversely, propagation of native inoculum may be tricky. Wild plants that are transplanted with the native soil will have a good supply of the proper inoculum (St. John 1998). Also many commercial formulations may only contain ubiquitously species such as *Glomus intraradices* (St. John 2000). These species are generalists and may not provide the optimum benefit to the plant if it requires a specific host. The native fungi to a particular site may not be commercially available. Furthermore, local phenotypic variations may exist that vary within the species; and species composition may vary during different seasons.   Ultimately, the best choices may involve choosing fungi native to the site, or obtaining fungi from soils similar to the restoration site. This will involve researching the most appropriate fungal species for the desired host plants

Fabric Mulch

Mulching is a long-established practice that is credited with many benefits to agricultural and landscape plants: reducing soil temperature fluctuation, enhancing appearance, conserving moisture, and suppressing weeds. Landscape fabrics have been used for many years for these purposes. Sheets of black polyethylene are one type of fabric mulch, but they are not permeable to water and air. Woven and meshed polymer fabrics have the advantage that they are permeable. Research on the efficacy of landscape fabrics is scant. One study compared two woven and six meshed or perforated non-woven landscape fabrics for the ability to suppress six weed species (Martin and others 1991). The authors concluded that spun-bound non-woven fabrics were superior to meshed non-woven fabrics. The brands of woven fabrics tested also did very well overall in preventing emergence and suppression of growth of the weed species, which included Johnsongrass (*Sorghum halepense*) and Bermudagrass (*Cynodon dactlyon*). Generally, polypropylene will degrade quickly when exposed to ultraviolet light, which prevents its use as a top mulch layer. Some products contain a coating which allows them to resist the damaging effects of exposure to sunlight (Martin and others 1991). The Kansas Forest Service recommends that a product have a guarantee that it will last a minimum of five years (Atchison and Ricke 1996). They also recommend a substrate weight of at least three ounces per square yard, a burst strength of at least 325 pounds per square inch, and a thickness of at least fifteen mils to be able to withstand deer trampling (Atchison and Ricke 1996)

CHAPTER 3

ASSESSMENT FOR CHARACTERIZATION OF THE SITE

Background

Archaeological evidence shows that human inhabitation in the area dates back almost 12,000 years. Small bands of Native Americans made temporary camps along the Elm Fork of the Trinity River, such as the Clovis-era Lewisville and Aubrey Sites (Ferring and Yates 1997). Later inhabitants included the Caddo, Kichai, Wichita, Kiowa and Comanche cultures (Lebo 1995). European-American settlers began arriving in the north Texas area in the 1840's. Bottomland forest was often the first location sought out, due to fertile soils and access to lumber, water and game. Anecdotal accounts indicate that parts of the LLELA property was under cultivation of cotton for roughly fifty years, and cattle grazing spanned another fifty years (Barry 2003). The impoundment of the Elm Fork of the Trinity River began in 1928 with the construction of the Lake Dallas dam. In 1948 construction began on the Garza-Little Elm dam, and was completed in 1955. The river was impounded in 1954 (Handbook of Texas Online 2005). In 1957 the old Lake Dallas dam was breached to form Garza-Little Elm Reservoir; today it is referred to as Lewisville Lake and dam. In 1987, the Elm Fork was impounded in the northern part of Denton County to form Ray Roberts Lake (USACE 2005).

These activities have had profound impacts on the local bottomland hardwood ecosystems, specifically on the vegetation communities, wildlife populations, soil stability, and the hydrology.

Objectives

In restoration projects, knowledge of the history of the site is vitally important for both understanding how the current conditions came to be as well as what options there are for restoration goals (Egan and Howell 2001). Restoration projects should begin with an environmental assessment to be used as baseline data. Baseline data can be compared to historic conditions or another reference ecosystem. While collection of this data was not possible at the beginning of the USACE study, it was still collected from the site and surrounding area to characterize the site and contribute to the knowledge base. To assess the current status of the site and to inform restoration efforts, data and information was collected in three categories: site history, soil parameters, and plant communities and local ecology.

Materials and Methods

Soil Survey and Presence of Mycorrhizal Fungi

The Soil Survey is a useful document that gives general information about the properties and distribution of soil series in the area. However, to have accurate data for a specific site, soil parameters must be field checked. Soil samples were collected to assess several physical, chemical, and biological characteristics. For most parameters, samples were sent to the Texas A & M Soil, Water, and Forage Testing Laboratory in College Station, Texas. A total of four samples were collected to be sent to the lab. Each sample represents one plot in the tree planting study area (Ash-DRIWATER®, Ash-Control, Ash-Mulch, Oak-TerraSorb®) and was made up of five subsamples, which were mixed in a bucket. The samples for the mycorrhizal analysis were taken on a separate occasion and were handled separately. To take the sample, a shovel was used to dig a hole six to eight inches deep, and then a slice was made from the edge of the hole. A one inch-wide core was taken from the slice.

The soil horizon description may be less relevant for the Vertisols of LLELA than for other soil types. According to the NRCS, “the shear failure that forms slickensides in vertisols also disrupts the soil to the point that conventional soil horizons do not adequately describe the morphology.” (Burt 2004)

The parameters tested at the Texas A & M soil laboratory included: pH, Nitrate (NO_3), phosphorus, potassium, magnesium, sodium, sulfur, conductivity, texture, organic matter, and organic carbon. All methods are documented on the Soil, Water, and Forage Testing Laboratory website (Texas A & M 2006). The elements P, K, Ca, Mg, Na, and S are extracted using the Mehlich III extractant and are determined by ICP (inductively coupled plasma-atomic emission spectroscopy).

pH is assessed by making a 1:2 soil-to-water extract of soil using de-ionized water. pH determination is made by using a hydrogen selective electrode.

Nitrate and nitrogen are extracted using a 1 N KCl solution. Nitrate is assessed by reduction of nitrite to nitrate using a cadmium column followed by spectrophotometric measurement.

Organic carbon is determined using a total carbon analyzer where the sample is reduced in an ignition furnace at 650 degrees Celsius. Organic matter is estimated by multiplying the percent organic carbon by a factor of 1.724 (Nelson and Sommers 1982). Organic carbon levels can also be informative for restoration purposes. High

OC indicates return of plant material such as leaf litter to the upper soil horizons (Stanturf and others 2001).

Cation exchange capacity (CEC) is defined as the sum total of exchangeable cations per unit weight of dry soil. It can be thought of as the availability of nutrients to plants. It is currently expressed as a value of centimoles of charge per kilogram. Effective CEC rises as pH increases. In neutral or alkaline soils, the cation exchange sites on the clay crystal lattice hold mostly Ca^{2+}, Mg^{2+}, and K^{+} (Brady and Weil 2004). There are several chemical approaches to measuring CEC, but they are time consuming and not routinely done. In this case CEC was estimated by a method that incorporates the type of clay colloid present, percent clay of the soil texture fraction, and percent organic matter (Brady and Weil 2004). The vertisol soils of the Ovan series contain montmorillonite clay, a smectite of the 2:1 type expanding silicate clays. So a CEC for smectite clays of 100 centimoles of charge per kilogram was used in this estimation (Brady and Weil 2004).

Bulk density was estimated following Rawls (1983). This approach uses percent organic matter plus the soil texture fractions of sand, silt, and clay to approximate the soil bulk density. The equation places the average organic matter bulk density at 0.224 g/cm3 and mineral bulk density is determined from a texture triangle that uses percent sand and percent clay.

To determine whether the soils are hydric or if hydric conditions periodically occur, soils were examined for redoximorphic features such as mottles or nodules.

Presence of mycorrhizal fungi was also investigated. The procedure for extracting glomalean spores and hyphae from soil samples follows that of Brundrett and others (1996). Three soil samples were taken from the study area; one was from an oak plot and two from ash plots. A fourth sample was taken from under an established Shumard oak in an area of sandy soil that was not in the study area. The soil was washed through a series of sieves, all material smaller than 250 μm was retained for analysis. Samples were added to tubes, topped with water, and centrifuged for five minutes at 2000 rpm. The supernatant was discarded. A 50% sucrose solution was added to the precipitate, which was shaken on a touch mixer until the precipitate was dissolved. This was then centrifuged for one minute. The supernatant was then collected and vacuum filtered. The remaining material was placed in a Petri dish and examined under a microscope for presence of spores and hyphae. Photographs were taken of one sample under magnification.

Soil moisture was assessed on these samples using a gravimetric method where a sample is dried at room temperature, then placed in a porcelain crucible and dried in an oven overnight at 105°C. Percent moisture was calculated by dividing water weight from oven dry soil weight.

Plant Communities and Local Ecology

Vegetation Survey

Throughout the duration of the study, a list has been compiled for the site for all species observed to occur on the study site. The list, found in Appendix A, notes life duration, growth habit, whether it is native or introduced, wetland indicator status, and conservation coefficient. Approximately 62 vascular plant species in twenty-seven families are known to occur on the site. A voucher specimen was collected for most species. The authority for nomenclature is Shinners and Mahler's Illustrated Flora of North Central Texas (Diggs and others 1999).

A vegetation survey was performed in the fall of the second year of the study. Four thirty-meter transects were placed in randomly selected plots in the study area. A 0.87 m diameter hula hoop was used for the boundary of the quadrats. Ten quadrats were randomly located along the north side of the transect. Species were identified and abundance was recorded to calculate species density, and species frequency, and importance value. Importance value was calculated for each species by summing the relative abundance and the relative frequency (Brower and others 1990; Nixon 1975). Shannon's diversity index and Simpson's diversity index were calculated to compare native versus introduced species, and to provide community diversity values for comparison to reference sites. Natural logarithms (base *e*) were used for the calculations. These indices were calculated with MVSP software (MVSP 2006).

Tree Census

A complete census of all living trees within the study area was conducted. This information can be used to estimate the approximate time that woody growth has been established. Species was recorded; any specimen under 100 centimeters in height was considered a seedling. Any specimen under 4 centimeters diameter at breast height (DBH) (1.43 m) was considered a sapling. For any specimen over 4 centimeters DBH, DBH and height was recorded. Diameter at breast height (DBH) was measured with a DBH tape. All trunks with forked stems below DBH were counted as separate stems (USFS 2005). Height was estimated using a clinometer. The clinometer yields reading of percent slope. The percent slope to the base of the tree is subtracted from the percent slope to the top of the tree. The total percent slope is multiplied by the distance from the observer to the base of the tree which yields a measurement of height.

DBH measurements were placed in a regression specific to LLELA to estimate age of the trees. The formula for *Celtis laevigata* (sugar hackberry) is $y=0.453x + 7.706$. The formula for Fraxinus pennsylvanica (green ash) is $y=0.642x + 7.798$ (Buckallew 2007).

Site History (Historical Ecology)

A more complete ecological understanding of a site is accomplished through investigations of past history and land use. Activities such as archaelogical research, dendrochronology, palynology, viewing historic aerial photographs, conducting interviews, and searching General Land Office (GLO) surveys and other records are used to piece together the site history. Site history may inform by identifying soil disturbances such as cultivation, habitat change due to logging or forest clearing, and plants that may have been introduced to the site (such as agricultural crops and accidental introductions). Often this information is used to assemble a representation of the historic ecosystem (Egan and Howell 2001). This may then be used as a reference ecosystem for a restoration project.

For the study site at LLELA, several of these activities were conducted. Aerial photographs were acquired from the USDA Farm Service Agency, Aerial Photography Field Office. Local residents with knowledge of the site were sought out and interviewed, namely Dorothy Thetford (née Decker), who grew up near the site. Historic documents were reviewed, namely Edward Bates's *History and Reminiscences of Denton County*.

Results and Discussion

Soil Survey

See Table 2 for a summary of the results of the soil analysis.

The pH was consistent across all four sampled areas. The soil is moderately alkaline with a pH of 7.6 to 7.7. This is probably due to the presence of calcium carbonate in the soil.

Soil electrical conductivity is a measure of the soil to transmit an electric charge through concentration of ions. It is an indirect measurement of the salt content of a soil. Conductivity in the samples ranged from 0.140 to 0.204 deciSiemens per meter. These numbers indicate a low conductivity; a soil with greater than 4.0 deciSiemens per meter is considered a saline soil (Brady and Weil 2002).

Soil nitrogen is an important macronutrient for plant growth. It is a major component of amino acids, enzymes, nucleic acids, alkaloids, and chlorophyll. It is essential for carbohydrate use, and it is vital for root growth and development. In the soil, nitrogen is taken up in the forms of nitrate (NO_3^-) and ammonium (NH_4^+) ions. At the study site, nitrate ranged from 9 t o 31 parts per million, which is a low to moderate range for agricultural productivity.

Phosphorus is another vital nutrient in terrestrial ecosystems. It is a component of DNA, RNA, and ATP (adenosine triphosphate). The phosphorus in the soils at the study site ranges from 9-13 parts per million. For agricultural purposes, this is considered low to moderate. However this particular test does not distinguish between the various forms of phosphorus found in soils. Some forms are more soluble to plants than others. Mycorrhizal fungi are known to uptake phosphate ions and move them to plant roots (Smith and Read 1997).

Potassium occurs in the soil only as a positively charged ion, K^+. When taken up by plants, it does not become part of organic compounds. Rather it stays in the ionic form in solution in the cell, as well as acting as an activator for cellular enzymes (Brady and Weil 2004). Potassium helps plants cope with environmental stressors such as drought tolerance, cold hardiness, and resistance to diseases and insects. Potassium is taken up by plants in relatively large quantities. But up to 98% of the element in the soil can be in an unavailable form, bound in the crystal structure of minerals (Brady and Weil 2004). At the study site, the levels in the soil ranged from 374 to 427 parts per million. These levels are considered very high.

Calcium and magnesium are important macronutrients that are associated due to their common periodicity as elements that form cations with a charge of 2+. Calcium is taken up by plants in large amounts and is an important part of the structure of cell walls and woody tissues. Magnesium plays an important role in photosynthesis, as it is the central component of the chlorophyll molecule. The levels of calcium at the study site ranged from 11,283 to 14, 057 parts per million, levels considered excessive for agricultural production. We would expect high calcium levels for this soil series, as it is classed as calcareous. The magnesium levels range from 227 to 303 parts per million, which are considered very high.

Sulfur is another macronutrient with many roles in plants. It is a component of several amino acids and many enzymes. It is chemically associated with nitrogen. The sulfur levels at the study site range from 20 to 23 parts per million, a very high amount.

Sodium does not have much of a role for plant nutrition. It is a common element in soils, and an excess of sodium can cause problems for plant growth. The sodium levels at the study site range from 102-135 parts per million, a moderate amount.

Soil texture class is a designation based on the ratio of particle sizes (sand, silt, clay) in a soil, and determines some of the physical properties of that soil. Three of the samples from the study site are clay. The results from these sites are 54%, 48%, and 54%. This is consistent with the description of the Ovan Series in the Soil Survey, which states that the Ovan series ranges from 40 to 55 percent clay (Ford and Pauls 1980). The other sample is a silty clay, with 56 percent clay content. This sample may be from a patch of Frio silty clay, which can occur in higher areas of the Ovan map unit. The high clay content of these samples indicates that the shrink-swell properties of this soil are great.

Organic matter (OM) in a soil consists of a variety of living soil organisms, remains of dead organisms, and various organic compounds produced by these organisms. Organic matter makes up one to six percent of a typical soil (Brady and Weil 2004). It is an integral component of soil ecosystems. It contains nutrients, binds soil particles together, and is the source material for humus. Activities such as agriculture, overgrazing, and soil erosion can reduce organic matter in soils. Estimations of organic matter levels at the LLELA site range from 3.29-3.83 percent. This can be considered a moderate amount for this type of site. Typical values for Ovan clay are 1-3% for the top 27 inches of soil (Ford and Pauls 1980). Some Organic carbon represents the humic fraction of the soil, not particulate organics or mineralogical carbon (Brady and Weil 2004). The organic carbon content of the soils at the LLELA study site ranged from 1.91 to 2.22 percent.

Cation exchange capacity can be viewed as a potential to yield nutrients. Estimates for soil cation exchange capacity ranged from 54.70 to 63.33 centimoles of charge per kilogram of soil. This is consistent for vertisol soils (Brady and Weil 2004).

Bulk density values ranged from 1.368 to 1.447 grams per cubic meter. Some values of bulk density (samples 1, 2 and 4) are slightly lower that the range reported in the Soil Survey (1.40-1.50).

Spores and hyphae of mycorrhizal fungi were found in all four samples. They were not quantified or taxonomically identified.

Soil moisture readings were 5.01%, 23.4%, and 25.6% from the study area, and 13.3% from the sandy soil site.

No mottles, nodules, or other indicators of hydric soil conditions were observed.

Table 2. Results of soil chemical and physical analyses

	Sample 1	2	3	4
pH	7.7	7.6	7.6	7.7
Conductivity (dS/m)	0.186	0.204	0.140	0.177
Nitrate	11	9	12	21
Phosphorus	13	9	10	10
Potassium	435	374	427	420
Calcium	14057	11283	12372	12533
Magnesium	303	227	262	285
Sulfur	23	20	20	20
Sodium	135	102	131	132
Sand	12%	16%	4%	8%
Silt	34%	36%	40%	38%
Clay	54%	48%	56%	54%
Textural Class	clay	clay	silty clay	clay
Organic Matter	3.29%	3.35%	3.83%	3.69%
Organic Carbon	1.91%	1.94%	2.22%	2.14%
Bulk Density (gm/cm^3)	1.387	1.368	1.447	1.397
Cation Exchange Capacity ($cmol_c/kg$)	60.58	54.70	63.33	61.38

*Units are parts per million unless otherwise indicated.

Vegetation Survey

In the vegetation survey, twenty-four species in eleven families were found. Species were ranked by importance value and are presented in Table 3 with abundance, frequency, and importance value results. By species, *Ambrosia trifida* dominates the site, followed by *Bromus japonicus*, and *Iva annua.* These are all weedy, annual species, and *Bromus* is a non-native. Combined they represent approximately 55% of the vegetation as expressed by importance percentage.

Table 3. Results from vegetation survey at LLELA study site, Fall 2005

SPECIES	Abundance	Density (n/23.78 m^2)	Rel Density	Freq	Rel Freq	IV
Ambrosia trifida	1044	43.90	0.312	34	0.160	0.472
Bromus japonicus	860	36.16	0.257	29	0.137	0.394
Iva annua	575	24.18	0.172	16	0.075	0.247
Lathyrus hirsutus	168	7.06	0.050	25	0.118	0.168
Dracopis amplexicaulis	171	7.19	0.051	24	0.113	0.164
Solidago sp.	234	9.84	0.070	17	0.080	0.150
Torilis arvensis	117	4.92	0.035	11	0.052	0.087
Rumex crispus	40	1.68	0.012	11	0.052	0.064
Aster ericoides	31	1.30	0.009	11	0.052	0.061
Euphorbia bicolor	38	1.60	0.011	8	0.038	0.049
Croton monanthogynus	6	0.25	0.002	3	0.014	0.016
Phalaris caroliniana	7	0.29	0.002	3	0.014	0.016
Celtis laevigata	3	0.13	0.001	3	0.014	0.015
Sorghum halepense	7	0.29	0.002	2	0.009	0.012
Carex blanda	4	0.17	0.001	2	0.009	0.011
Lythrum alatum	20	0.84	0.006	1	0.005	0.011
Toxicodendron radicans	4	0.17	0.001	2	0.009	0.011
Gaura parviflora	3	0.13	0.001	2	0.009	0.010
Helianthus annuus	2	0.08	0.001	2	0.009	0.010
Cirsium texanum	2	0.08	0.001	2	0.009	0.010
Carex festucacea	10	0.42	0.003	1	0.005	0.008
Aster subulatus	1	0.04	0.000	1	0.005	0.005
Panicum capillare	2	0.08	0.001	1	0.005	0.005
Ulmus americana	1	0.04	0.000	1	0.005	0.005

Dominance by family and physiognomic class was determined by ranking importance values. By family, importance values were highest for Asteraceae (55.95%), followed by Poaceae (21.4%). The Fabaceae, Apiaceae, and Euphoribiaceae had moderately dominant populations as well. The remaining families had less significant populations. These results are illustrated by Figure 4. By physiognomic class, annual forbs dominate at 53%. This is followed by annual grass (20.8%), perennial forbs (14.3%), and annual herbaceous vines (8.4%) the remaining classes tree, perennial sedge, perennial grass, perennial woody vine, and biennial forbs were present at 1% or less. These results are displayed by figure 5.

The distribution of number of taxa by physiognomic class was calculated. This is presented in table 4. The number of taxa is dominated by annual forbs (26.2%), followed by trees (21.3%), and perennial forbs (19.7%). These results are presented in Table 4.

Figure 4. Vegetation dominance of the study site by family

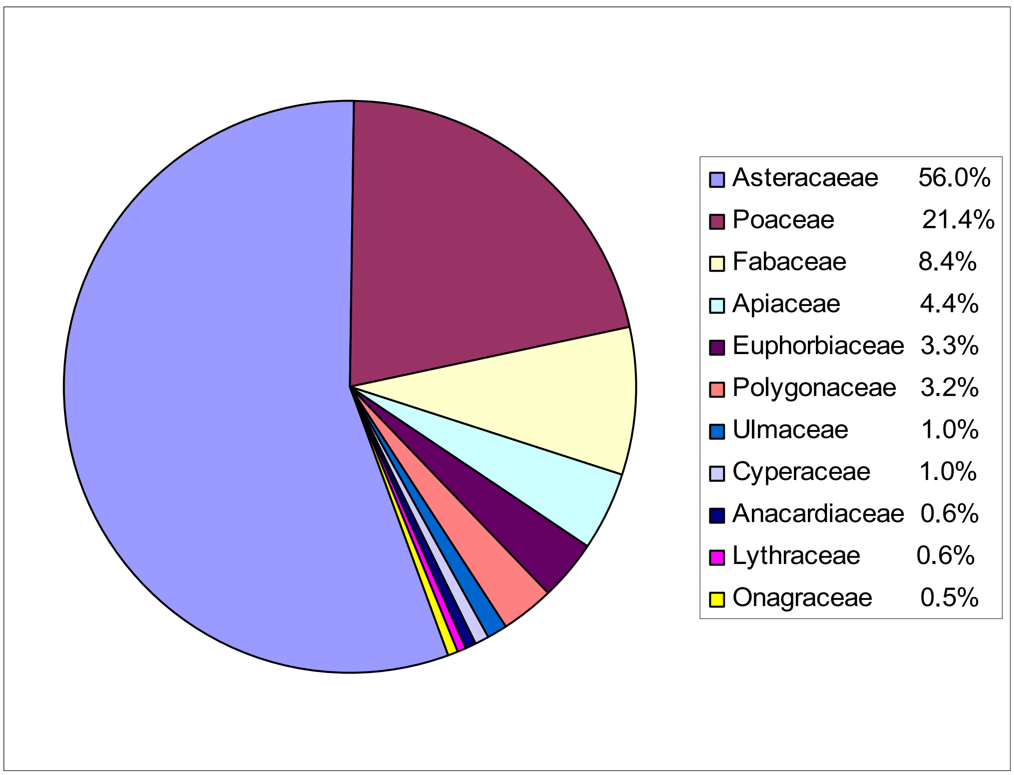


Figure 5. Vegetation dominance of the study site by physiognomic class

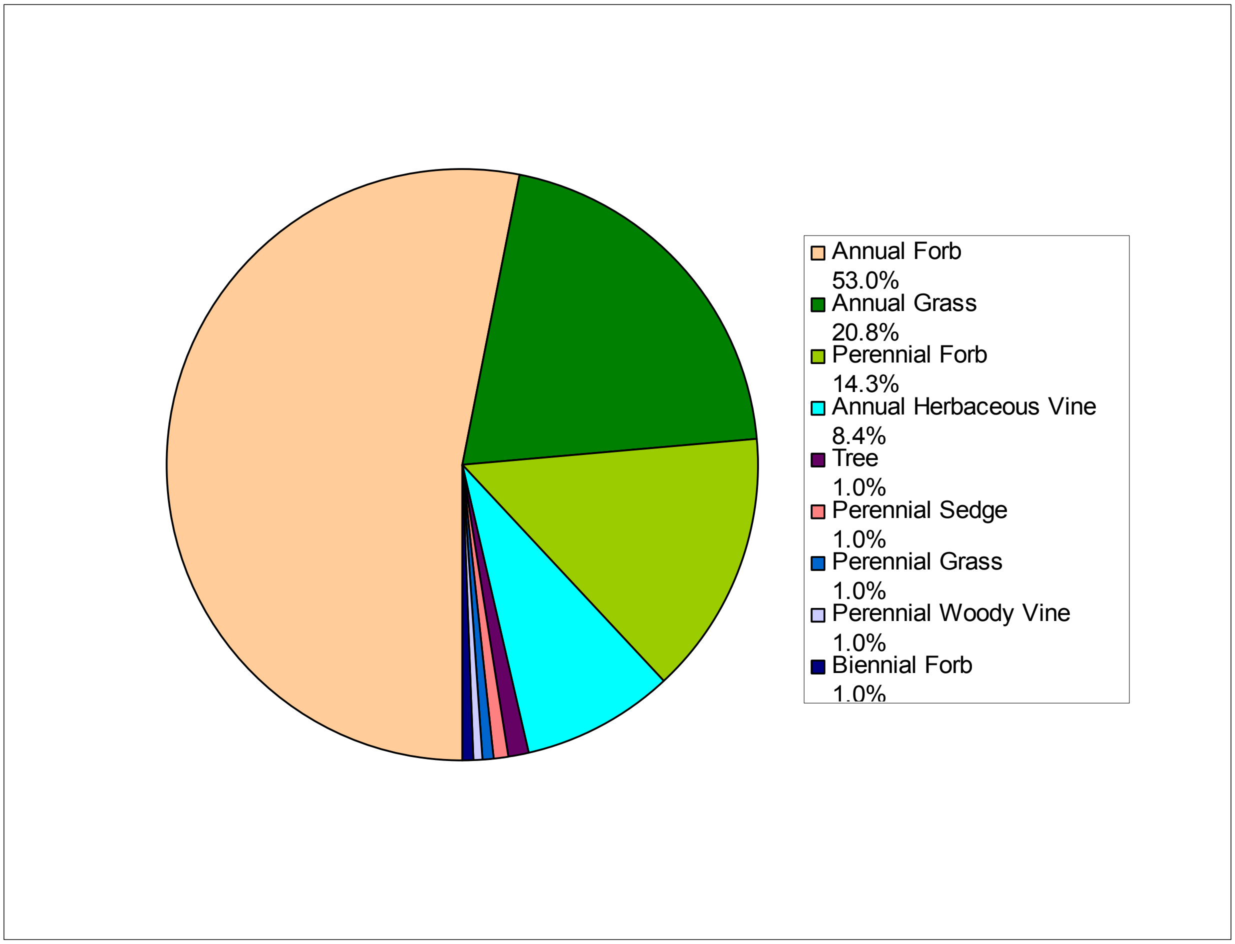


Table 4. Dominance of physiognomic class, by number of taxa

	Number of Taxa	% of Taxa
Annual Forb	16	26.2
Biennial Forb	3	4.9
Perennial Forb	12	19.7
Annual Grass	4	6.6
Perennial Grass	2	3.3
Annual Sedge	0	0
Perennial Sedge	4	6.6
Herbaceous Vine	2	3.3
Woody Vine	1	1.6
Shrub	4	6.6
Tree	12	21.3

Diversity values were calculated for the study site. For the total site, The Shannon-Weiner diversity index (H') is 1.899. The Simpson's dominance index is 0.786. The respective values were computed for native and introduced plant species. For Shannon's diversity, the native vegetation had a value of 1.432, where the introduced plants had a value of 0.796. For the Simpson's Diversity, the native plants had a value of 0.674 and the introduced had a value of 0.455. The results are summarized in Table 5.

Table 5. Shannon's and Simpson diversity indices for the study site

DIVERSITY SUMMARY			
TOTAL SITE			
Shannon's method			
Sample	Index	Evenness	n
Total site	1.899	0.597	24
Simpson's method			
Sample	Index	Evenness	Num.Spec.
Total site	0.796	0.83	24
NATIVE VS. INTRODUCED			
Shannon's method			
Sample	Index	Evenness	Num.Spec.
Native	1.432	0.495	18
Introduced	0.914	0.51	6
Simpson's method			
Sample	Index	Evenness	Num.Spec.
Native	0.674	0.714	18
Introduced	0.455	0.546	6

Wetland indicator status is derived from the US Fish and Wildlife Service (USFWS) report *National list of vascular plant species that occur in wetlands* (Reed 1988). It consists of a set of designations of how likely a given species is to occur in a wetland versus a non-wetland. There are five codes to indicate this probablility. Obligate Wetland indicator plants will occur in wetland in almost occurrences—a 99% probability. A Facultattive Wetland indicator has a probability of 67-99%, meaning it usually occurs in wetlands but is occasionally found in non-wetland areas. A Facultative Indicator is equally probable to occur on a wetland or a non-wetland (34-66% probability). A Facultative Upland plant typically occurs outside of wetlands (67-99% probability), but is occasionally found in wetlands (1-33% probability). An Obligate Upland indicator may occur in wetlands in other regions, but will almost always occur (99% probability) in non-wetlands in the region specified. In some cases, the deisnation is followed by a positive (+) or a negative sign (-). A positive sign more specifically designates a greater tendency toward occurrence in wetlands for a given region. A negative sign more specifically designates a lower tendency toward occurrence in wetlands for a given region. If there is lack of information regarding a species's status, then it is given a designation of No Inidcator. If a plant does not occur in wetlands in any region, it is not on the list (Reed 1988).

The wetland indicator status of each of the 62 plant species found at the site over the duration of the study has been determined, and is indicated in Appendix A. The results are varied across the range of categories. A total of fifteen species are Facultative, which makes up the largest percentage of species at the study site. The category with the second highest representation by species is Facultative Upland, comprising 23.4 % of the species. Four species (8.5%) found are Obligate Wetland. Seven other species are in the remaining wetland categories, which total 14.9%. The results are summarized in Table 6. The Wetness Rating (Coefficient of Wetness) comes from Ladd (1997) and is a numerical equivalent to the wetland indicator status of the USFWS.

Table 6. Wetland indicator status, by number of taxa found at the LLELA study site

Category	Wetness Rating (CW)	Number of Taxa	% of Flora
Upland	5	1	2.1
Facultative Upland -	4	4	8.5
Facultative Upland	3	11	23.4
Facultative Upland +	2	1	2.1
Facultative -	1	3	6.4
Facultative	0	15	31.9
Facultative +	-1	1	2.1
Facultative Wetland -	-2	2	4.3
Facultative Wetland	-3	4	8.5
Facultative Wetland +	-4	1	2.1
Obligate Wetland	-5	4	8.5

Of the sixty-two species observed at the site throughout the duration of the study (see Appendix A), fifty-one are native and ten are introduced. Regarding life span, twenty-four species are annual, thirty-five are perennial, and three are biennial. Forty-seven species have a wetland indicator status, while fifteen have no designation. Concerning physiognomic class, thirty-two species are forbs, four are shrubs, ten are graminoid, thirteen are trees, and three are vines.

Seven species found at the site are in the Fabaceae. This is of interest because many species in this family host nitrogen-fixing *Rhizobia* bacteria in root nodules. One tree, *Gleditisia triacanthos* (honey locust), is known to not fix nitrogen (USDA 2006).

Three of the species in the Fabaceae, *Lathyrus hirsutus*, *Melilotus officinalis*, and *Vicia sativa*, are non-native species. *Lathyrus hirsutus* is recognized as having high nitrogen-fixing value, and *Vicia sativa* is also known to fix nitrogen (USDA 2006).

Coefficients of conservatism (*C*) were assigned to species found at the site, for taxa for which it has already been assigned (Masters 1997). Most *C* values used here come from locally adapted designations from similar studies of the entire LLELA property (Buckallew 2007). Values for *C* in a range of zero to three can be considered non-conservative species, and values from four to ten indicate a conservative species. A Floristic Quality Assessment (FQA) for a particular site is determined by taking the mean of the *C* values for the species found at the site. Then a Floristic Quality Index (FQI) can be calculated by multiplying the mean of the C values by the square root of the total number of native species at the site (FQI = $C\sqrt{n}$).

For the LLELA site, the mean *C* was 2.46, and the FQI is 17.57. Values for *C* are found in Appendix A. Therefore this site can be considered generally not represented by conservative species.

Tree Census

A total of 13 species was found in the tree census. The species found, size classes, species abundance by class, and total abundance for each species is summarized in Table 7.

Results for species abundance and calculations for density, relative density, relative frequency, and importance value are found in Table 8. Results in this table are ranked by importance value. By this measure, the tree community is dominated by

Celtis laevigata. It is both the most numerous and the most frequently occurring species. This tree has an importance percentage of 32.5%. The other dominant species from the site are *Ulmus* sp., *Gleditsia triacanthos*, *Sideroxylon lanuginosum*, and *Crataegus* sp. This *Ulmus* species is either *U. alata* (winged elm) or *U. crassifolia* (Cedar elm). These specimens had the corky 'wings" known on *U. alata*, but these are known to occur on *U. crassifolia* as well. The most positive diagnostic feature to tell these two species apart is the flowering phenology. *U. alata* flowers in the spring and *U. crassifolia* flowers in the fall. No flowering has yet been observed in these trees; they may not yet be mature enough to flower. The other species of the *Ulmus-Fraxinus-Celtis* association are present, but not in large numbers: *Ulmus americana* and *Fraxinus pennsylvanica* have importance percentages of 4.5% and 3.0%, respectively.

Results of measurements of height and diameter at breast height from the tree census are presented in Table 9.

The tallest species at the site is *Maclura pomifera* at 5.61 meters mean height. The specimen with the tallest maximum height is *Celtis* at 7.29 meters. *Maclura* has the largest mean DBH at 12.53 centimeters, as well as the largest maximum DBH at 17.40 centimeters.

By size class, seedling and sapling consistently outnumbered adult trees among all species. In the most dominant species *Celtis laevigata*, 68.4% were saplings, 22.5% were adult, and 9.1% were seedlings.

In general, the canopy is open and tree species are fairly evenly distributed. Tree cover for the entire study area is estimated at 20-30%.

Age of the trees was estimated by inputting DBH into a regression calculated for hackberry and green ash at LLELA (Buckallew 2007). For hackberry, the estimated mean age is 10.76 years, and the estimated maximum age is 13.19 years. This places the establishment of the hackberry trees at the years 1992-1995. For the green ash, the estimated mean age is 14.49 years, and the estimated maximum is 15.82 years. This dates the establishment of the green ash to 1990-1992.

Table 7. Results of tree census

SPECIES	SIZE CLASS	ABUND. BY CLASS	% BY CLASS	SPEC. TOTAL
Celtis laevigata	seedling sapling adult	21 158 52	9.1 68.4 22.5	231
Crataegus sp.	sapling	8	100	8
Fraxinus pennsylvanica	seedling sapling adult	3 2 2	42.9 28.6 28.6	7
Gleditsia triacanthos	seedling sapling adult	12 69 4	14.1 81.2 4.7	85
Ilex decidua	shrub	2	100	2
Juniperus virginiana	sapling	1	100	1
Maclura pomifera	sapling adult	1 1	50 50	2
Prunus rivularis	seedling sapling	2 1	66.6 33.3	3
Sapindus saponaria	seedling sapling adult	18 3 1	81.8 13.6 4.5	22
Sideroxylon lanuginosum	seedling sapling	7 10	41.2 58.8	17
Ulmus americana	seedling sapling adult	2 6 2	20 60 20	10
Ulmus sp.	seedling sapling adult	10 82 5	10.3 84.5 5.2	97
Zanthoxylum clava-herculis	sapling	1	100	1

ABUND BY CLASS—Species abundance by size class
% BY CLASS—Percentage of abundance by size class
SPEC TOTAL—Total number of trees for each species

Table 8. Community measures for the tree census

SPECIES	Abund	Density (stems/ha)	Rel Dens	Rel Freq	IV
Celtis laevigata	231	228.7	.48	0.17	0.65
Ulmus sp.	97	96.0	.20	0.17	0.37
Gleditsia triacanthos	85	84.2	.17	0.16	0.33
Sideroxylon lanuginosum	17	16.8	.03	0.12	0.15
Crataegus sp.	8	7.9	.02	0.09	0.11
Ulmus americana	10	9.9	.02	0.07	0.09
Sapindus saponaria	22	21.8	.05	0.03	0.08
Fraxinus pennsylvanica	7	6.9	.01	0.05	0.06
Prunus rivularis	3	3.0	<.01	0.03	0.04
Ilex decidua	2	2.0	<.01	0.03	0.04
Maclura pomifera	2	2.0	<.01	0.03	0.04
Juniperus virginiana	1	1.0	<.01	0.02	0.02
Zanthoxylum clava-herculis	1	1.0	<.01	0.02	0.02

Abund—Species abundance, **Rel Dens**—Relative Density,
Rel Freq—Relative Frequency, **IV**—Importance Value

Table 9. Summary of height and diameter measurements for the tree census

SPECIES	Mean Hght (m)	Max Hght (m)	Mean DBH (cm)	Max DBH (cm)
Celtis laevigata	4.82	7.29	6.75	12.10
Ulmus sp.	3.80	5.04	7.51	10.90
Gleditsia triacanthos	5.48	6.38	7.24	9.40
Sapindus saponaria	3.57	3.57	4.00	4.70
Sideroxylon lanuginosum	--	--	--	--
Ulmus americana	4.95	6.37	5.78	7.40
Crataegus sp.	--	--	--	--
Fraxinus pennsylvanica	4.53	5.6	10.43	12.50
Prunus rivularis	--	--	--	--
Ilex decidua	--	--	--	--
Maclura pomifera	5.61	5.61	12.53	17.40
Juniperus virginiana	--	--	--	--
Zanthoxylum clava-herculis	--	--	--	--

Site History

European-American settlement in Denton County was opened up in 1841 after the establishment of Peter's Colony, and with that came abrupt land use changes. Stewart's Creek Settlement was established in 1844 at a location just east of the Elm Fork at the mouth of Stewart Creek (Bates 1976). The Ritter family settled nearby as part of this settlement, making an important ford across the Elm Fork (Bates 1976). This settlement was on the present-day LLELA property. The Ritters established a cemetery at least as early as 1860, which remains in place today. The study site lies immediately south of the Ritter Cemetery. The land on which the study site presently sits belonged to the Ritter and Decker families during the late nineteenth and early twentieth century (Thetford 2006). Land use on their property during these years varied, ranging from cattle grazing to cultivation of crops of vegetables and cotton (Thetford 2006).

Aerial photographs from the years 1958, 1970, 1980, 1989, and 1995 have been examined to determine the land use during recent decades. Also, aerial photographs from the years 1999, 2001, and 2003 were viewed online on the North Central Texas Council of Governments (NCTCOG) website. The area where the study site is today appears to have been used only for agricultural purposes during the span of time when these photographs were taken, namely cultivation of hay. The appearance of the field shows a pattern of clean lines that appears when a grassy field is mowed by a tractor, such as in the cultivation of hay rather than harvest of row crops or fine grain crops (McGregor 2006). This could also occur when the soil is plowed by a tractor. Sometimes, an 'X' shaped pattern is also visible in the field, caused by darker areas at the corners where the tractor has turned 90 degrees when mowing in a spiraling square pattern. This evidence of recent mowing is visible in all images up to the year 1980. The 1989 image does not look freshly mowed, but the ‘X’ pattern is visible. The same ‘X’ pattern can be clearly seen in the 1995 image. By 2001 the pattern is faint, and by 2003 is almost imperceptible. This could indicate that hay cultivation in the field stopped sometime around the mid- to late 1980’s and the field was left fallow. By the time of the 1989 image, a less homogenous and more natural pattern of vegetation is visible in the field. Another factor that suggests hay cultivation is the presence of a hay rake attachment for a tractor that had been abandoned in the field.

This evidence suggests that the area of the study site had been under some type of agricultural or ranching activity since the 1850’s. At least since the 1950’s, a primary activity has been hay cultivation. The last instance of plowing the soil or presence of livestock is unknown. It appears that hay cultivation ceased during the mid to late 1980’s, allowing the site to return to a natural progression of secondary succession.

Conclusions

Today the site appears to be in an early stage of succession following abandonment from agricultural activities. The trees on the site are mostly seedlings and saplings; the adult trees are roughly ten to fifteen years old. This places tree establishment at some point in the early 1990’s. This is fairly consistent with the patterns in the aerial photos showing a returning of a natural vegetation pattern to the field. Following the general trend of succession, If the field was abandoned in the late

1980's, the first few years of natural regeneration would have been strictly herbaceous annuals. Then grasses would have come in, followed by tree seedlings.
The woody species returning are the same as those found in a bottomland hardwood forest communitiy.

The current herbaceous community is mostly herbaceous annuals. Most species are not conservative, and a few are aggressive invaders (namely *Sorghum halepense*). Nine conservative species were found, three of them sedges. Four obligate wetland and seven facultative wetland indicator species were found on the site, indicating that it has a tendency toward wet conditions.

The parameters of the soil evaluation show that the LLELA site is mostly consistent with the Soil Survey of Denton County. The site does not appear to have been part of the donor site for construction of the dam. The heavy clay soil is moderately alkaline and low in salinity. Overall, the site is not nutrient deficient. However, nitrogen and phosphorus are low to moderate, which is to be expected on a former agricultural site. The other nutrients have very high levels: potassium, calcium, magnesium, and sulfur.

Organic matter appears to be moderate, and is slightly higher than ranges reported for the Ovan series in the Soil Survey. Perhaps OM was removed by decades of agricultural activities at the site, but return of natural vegetation for fifteen or twenty years may have allowed the site to accumulate organic matter.

During bottomland forest restoration project monitoring, an increase in organic carbon levels can indicate succession (Stanturf and others 2001). Plant material is returning to the organic and A soil horizons from leaf litter; meanwhile less soil disturbance is occurring with the absence of soil tillage.

Soil compaction is a prominent problem in old-fields (Whisenant 1999). Bulk density can be an important measure of soil compaction, as a decrease can indicate soil recovering from cessation of traffic from heavy machinery or vehicles, increase in woody roots (which improves soil porosity), and protection of the soil surface from the impact of raindrops through development of ground vegetation or forest canopy (Stanturf and others 2001). Many hardwood trees of bottomland ecosystems do not grow well if bulk density exceeds 1.4 grams per cubic meter (Allen and others 2001). The results from the study site reveal that bulk density hovers just at or below this critical threshold. Therefore soil compaction will be an important consideration for restoration efforts. The results from the study site are just an estimate; for more accurate readings, a soil penetrometer is recommended.

Gilgai and the wide cracks that develop on Vertisols maintain important structural roughness that slows rapid runoff of water and increases infiltration. Erosion does not appear to be much of an issue at the study site, since it is relatively flat.

An indigenous mycorrhizal community is present both on the study site and off site. Further tests could be done to identify the taxa present at the site, quantify the number of spores per sample, and the degree of infection in roots. Taxonomic identification could reveal whether the fungi present are generalist or specialist, further revealing any potential interactions between fungus and host.

In short, the site is an old-field recovering from decades of agriculture and grazing impacts. The soils today are moderately fertile, but remain compacted. The plant community is dominated by weedy annuals in the Compositae and Poaceae. A few sedge species exist on the site; several of them have conservative status. The whole range of wetland indicator status is reflected in the species composition. Trees have been colonizing the site for the last ten to fifteen years. The species composition resembles that of bottomland hardwood forests. If left alone, in time the trees would increase their dominance and eventually a closed-canopy would develop. Many robust forbs and grasses, such as *Ambrosia trifida*, *Iva annua*, and *Sorghum halepense*, would be shaded out.

CHAPTER 4

SEEDLING ESTABLISHMENT STUDY

Introduction

Bottomland and riparian forest revegetation and restoration projects in Texas inherently face formidable challenges. Establishment of seedlings is a critical time for revegetation projects due to their vulnerability to environmental stressors. The long, hot and dry summers often present drought conditions, which is the main cause of mortality and reduced vigor of tree species in planting projects. Irrigation and other intensive cultivation practices may be logistically difficult due to remoteness and cost constraints. Several commercially available products may offer enhanced survival in this type of project. However, these products have not been extensively tested under a variety of field conditions. Four products that are of interest are two types of water-retaining gels, a mycorrhizal inoculant, and polypropylene fabric mulch.

Superabsorbent or water-retaining gels can be synthetic, such as super-absorbent potassium polyacrylamide polymers. Terra-Sorb® is one such product; it is designed to hold up to 200 times its weight in water and slowly release moisture to the root zone over time (up to several years).

Another type of superabsorbent is DRiWATER®, which is a patented gel-like product that is composed of 98% water and 2% food-grade cellulose and alum. It is a non-toxic product that provides water to plant roots as naturally occurring soil bacteria slowly break down the gel. DRiWATER® is designed to provide water continuously for up to 90 days.

DIEHARD™ Root Dip is an inoculant product for bare root treatment that contains live cultures of low host-specificity fungi and bacteria combined with other ingredients to aid survival and growth. The DIEHARD™ Root Dip contains both endomycorrhizal and ectomycorrhizal species. The endomycorrhizal fraction consists of multiple strains of live spores of *Glomus mossae*, *G. intraradices*, *G. fasciculatum*, *G. dussii*, *G. clarum*, *G. deserticola*, and *G. microaggregatum*. The ectomycorrhizal fraction (which principally colonizes pines, oaks, and a few other hardwoods) consists of sprores of *Pisolithus tinctorius* and *Rhizopogon* sp. (Horticultural Alliance 2003). Other ingredients in the product include humic acids, *Trichoderma* propagules, extracts of yucca and sea kelp, root promoting vitamins, cross-linked polymer superabsorbent gel, and beneficial bacteria (*Bacillus* spp., *Pseudomonas* spp., and *Streptomyces* spp.) (Horticultural Alliance 2003).

Lumite® Fabric Mulch is a black woven polypropylene product that is designed to suppress competitive vegetation growth and conserve soil moisture. Synthetic fabric mulch was chosen over shredded tree mulch to eliminate any possible confounding allelopathic factors that may be present. Lumite® is water-permeable and has a five-year guarantee against ultraviolet deterioration.

Objectives

This project assessed the performance of the four treatments on the survival and growth of two species of trees native to bottomland forest in north-central Texas, Shumard oak (*Quercus shumardii*) and green ash (*Fraxinus pennsylvanica*). The four treatments consisted of the Terra-Sorb® polyacrylamide gel, DRiWATER®, the DIEHARD™ mycorrhizal inoculant, and the Lumite® mulch fabric squares. Additionally, a control group receiving no treatment was established for experimental comparisons. The duration of this study was two years, with periodic assessments of survival, as well as growth measurements of height and diameter.

Species

Shumard oak (*Quercus shumardii*) is a large, deciduous southern lowland tree of the black oak group that ranges from North Carolina west to the eastern half of Texas and north to Indiana and Ohio (Edwards 1990). It is found on moist, well-drained soils typical of terraces of bottomlands. It does not occur in large, pure stands but is found as widely spaced individuals (Simpson 1988). It is found in fifteen SAF forest cover types, including SAF 93, *Celtis laevigata—Ulmus americana—Fraxinus pennsylvanica* (Sullivan 1993). It is also associated with *Carya aquatica* (water hickory), *Carya cordiformis* (bitternut hickory), *Carya ovata* (shagbark hickory), *Fraxinus americana* (white ash), *Quercus falcata* (southern red oak), *Quercus nigra* (water oak), and *Ulmus alata* (winged elm) among others (Sullivan 1993; Edwards 1990). Typical soils for Shumard oak include alluvial and colluvial sites in the Alfisol, Inceptisol, and Vertisol soil orders (Edwards 1990). It is weakly intolerant of flooding (Hosner and Boyce 1962), so it is not typically found on the lowest river bottoms or flats. However, it is somewhat drought tolerant (Sullivan 1993). It is classified as a facultative wetland indicator species (Reed 1988). Although intolerant of shade, it is considered to be uncommon on early-successional sites; it is thought to be a gap colonizer of mature forests (Sullivan 1993; Nixon 1975). Shumard oak has great value for wildlife. Mature trees produce acorns every two to four years which provide mast for many species of birds and mammals such as wild turkeys, waterfowl, songbirds, white-tailed deer, and squirrels (Sullivan 1993). It also provides browse for white-tailed deer (Sullivan 1993).

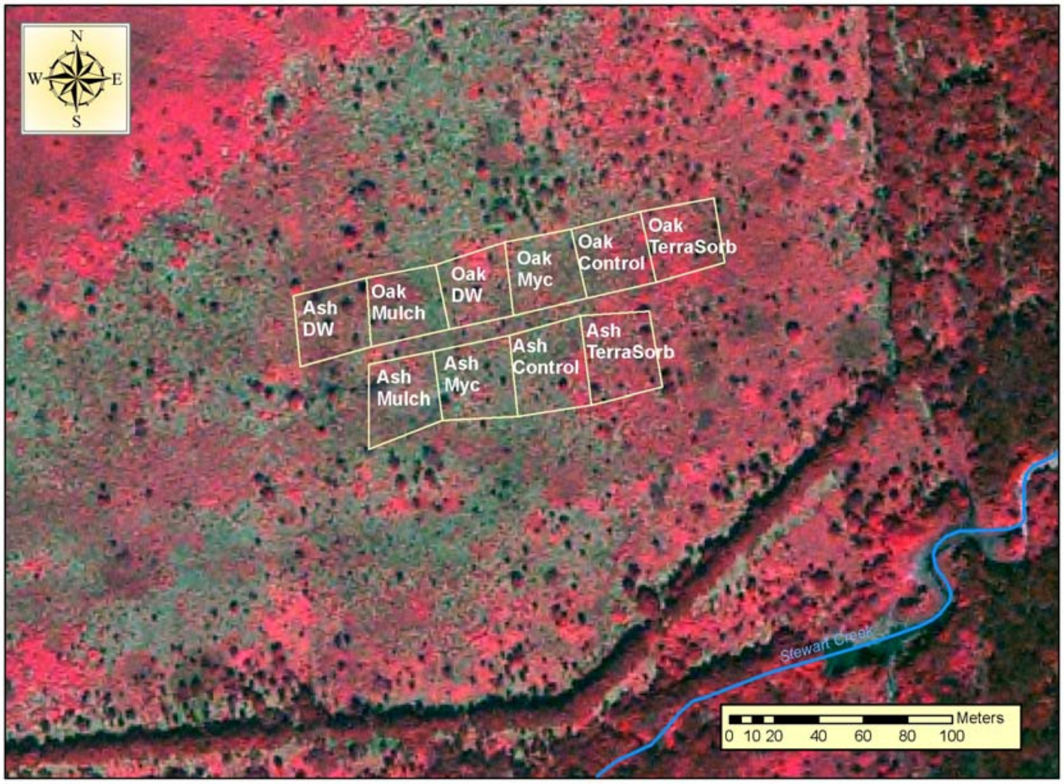
Green ash (*Fraxinus pennsylvanica*) is a fast-growing, medium-sized deciduous tree in the olive family (Oleaceae). It has a widespread distribution, ranging across most of eastern North America (Kennedy 1990). It is an adaptable species, occurring on a range of soil types, moisture regimes, and climactic types. It is typical of alluvial bottomlands along streams and rivers. It is very tolerant of flooding, and is common on sites that remain flooded for many months (Kennedy 1990, Hosner and Boyce 1962). It is also moderately drought-resistant (Rosario 1988). It occurs in twenty-two of the SAF cover types, and is a dominant in SAF 93, *Celtis laevigata-Ulmus americana-Fraxinus pennsylvanica* (Sullivan 1993). Common associates include: *Acer negundo* (boxelder), *Carya illinoinensis* (pecan), *Platanus occidentalis* (American sycamore), *Populus deltoides* (eastern cottonwood), and *Salix nigra* (black willow) (Kennedy 1990). The seed is a samara that is wind-dispersed. It occurs early in succession, and is tolerant of competition from forb and shrub species (Rosario 1988). Green ash is tolerant of shade in the southern part of its range (Kennedy 1990). The species has significant wildlife food and cover value. It provides browse to deer and rabbits, and the samaras are consumed by numerous small mammals and birds (Rosario 1988). Green ash forms mycorrhizal associations; at least one species is known to stimulate growth (Andersen and others 1987).

Materials and Methods

One thousand bare-root trees were purchased from the Oklahoma Department of Forestry: 500 Shumard oak and 500 green ash. The planting area was roughly divided into two areas, one for each species. Each species area is further divided into five blocks, for each treatment and for the control group. Each treatment was randomly assigned to a block. The blocks were demarcated with 60-inch T-posts at each corner. See Figure 6 for the placement of the treatment blocks at the study site.

In March 2004, the trees were planted by volunteers and LLELA staff. One hundred trees were planted per block. A color-coded 8 x 5-inch vinyl flag on a 36-inch wire post was placed into the ground next to each seedling to ease finding the tree during the growing season. Each block is 1011 m^2 (0.25 acre). The total area planted is 1.01 hectares (2.5 acres). Spacing between trees was to be no less than 3.05 meters (10 feet).

Figure 6. Placement of treatment blocks at field site. The background is from 2004 NAIP imagery



Application

Fine-grade Terra-Sorb® is mixed at a rate of 1 lb. per 25-40 gallons of water (1 kg. per 200-350L). One pound treats 15,000 bare root seedlings. For an application of this size, only a few ounces of the powder were necessary in a five-gallon bucket of water. The mixture sat for one hour until it was the consistency of gravy. The gel should be a thickness that achieves maximum adherence to the roots. In the field, the seedlings were stored and carried in the bucket covered in Terra-Sorb® to keep the roots from drying.

Application of the DIEHARD™ Root Dip mycorrhizal inoculant follows a similar technique as the polyacrylamide gel. One 15 oz. bag treats 3,000 trees. The manufacturer recommends mixing contents with 10 gallons of water, and let stand 15-30 minutes until the gel resembles thick gravy that adheres to the roots when dipped into the mixture. In this case, I used 2-3 oz. of the powder to 2-3 gallons of water. To prevent the roots from drying, seedlings can be stored with roots covered in gel until ready for planting.

The DRiWATER® comes in 'gel pacs' that are to be cut open and inserted into a plastic tube planted next to the tree. The bottom of the tube should have direct contact with the root mass. After the soil has been backfilled around the tree, the tree must be watered through the tube before the gel pac is inserted. DRiWATER® is available in several different sizes depending on the application. In this case, the 3-inch diameter tubes are used. After watering, the gel pac is cut open and the DRiWATER® is inserted into the tube, and the plastic casing is discarded. Then the cap is placed on the tube. One gel pac application is generally good for 90 days; during the growing season the gel pacs need to be replaced every 90 days or when the DRiWATER® tube is empty, depending on field conditions.

For this project, the 4 x 4-foot size Lumite® Fabric Mulch squares were used. A slice was made in the center of the square to form an opening for the tree. The fabric square was then placed over the planted tree. Five 8 x 2-inch, 11-gauge wire staples were used to secure the square to the ground: one in each corner and one in the center.

In March 2004, LLELA staff and undergraduate student volunteers from Environmental Science classes assisted with the tree planting activity. The weekend of the planting, the soil was quite moist from recent rain and was so sticky as to be difficult to dig. A few volunteers came out the following weekend to finish up, and by then the soil had begun to dry out to a rock-hard consistency.

No watering or maintenance was performed on this project, except for the replacement of DRiWATER® gel pacs when necessary plus the watering that accompanies the application of the gel pacs.

Later in the first summer, each tree was given an aluminum tag with an individual code for identification and recordkeeping purposes.

Survival Monitoring

During 2004, survival monitoring took place late spring after the vegetation had fully emerged (June) and in fall before the first freeze (October-November) to assess performance after the summer. In 2005, again there were two monitoring events (June-July and October-November). The status of each tree was recorded as either alive, dead, or not found. During each monitoring event, field conditions were noted and photographs were taken at all four corners of each of the ten plots.

Assessments of Growth

To assess growth of the trees, measurements were taken of height and diameter. Height of the seedling was measured with a meter tape from the base at ground level or at the root collar if the soil had eroded or settled significantly. Diameter was measured with a caliper at ground level or at the root collar. The initial set of measurements was taken in January 2005. Final measurements were taken January 2006. The time span of growth to be measured covered approximately one year.

DRiWATER® Application for Year Two

During 2005, each DRiWATER® plot was divided in half to assess whether the DRiWATER® applications are effective if given a second year. Approximately half of the living trees received an application of DRiWATER® gel pacs, 12 in the oak plot and 39 in the ash plot. The first application did not occur until mid-May, as the DRiWATER® plots had standing water through March, and the soil was quite moist through April and into May. The second application occurred in August. Survival of the trees that received gel pacs was noted during the final round of survival monitoring in October.

Data Analysis

A 2 x 2 chi-squared contingency analysis was performed to test the hypothesis that survival is contingent upon treatment. In the instance of expected count cell frequencies totaling 5 or less, a log-likelihood test (G-test) was employed.

A tree was only given the status ‘alive’ or ‘dead’ if the state of the tree could actually be confirmed. In some cases, the flag marking the tree is located, but no tree is visible. In other cases, the flag marking the tree is missing or was completely obscured by vegetation, and that tree was not located as well. In both of these instances, the individual tree is considered ‘not found’.

Growth measurements of height and diameter were tested for a normal distribution using a Shapiro-Wilks test. Some sets of data were non-normal, so all sets of growth data were performed with the same test for consistency. The non-parametric Kruskal-Wallis one-way multiple sample test was employed to test the hypothesis that the soil amendments enhance height and diameter between treatment and control. The test was repeated for year one and for year two. If results were significant, the test was followed by a Tukey Multiple Comparison Test on ranked values (α=0.05) to determine the statistical significance of pairs of treatments.

For growth of trees that received a second-year treatment of DRiWATER®, a Mann-Whitney U test was performed assess the difference between treatment and no treatment.

Significance of all tests was determined at α =0.05. All statistical analyses for the tree study were computed using SAS software, version 8.2 (SAS Institute 2006).

A second set of hypotheses was tested in the DRiWATER® plots. One, that survival is contingent on a DRiWATER® application during the second year. In this case, a log-likelihood (G-test) was performed on the results using SAS. The other examined growth of the trees that received the second year treatment versus those that did not. In this case, height and diameter growth was a derived variable where year one was subtracted from year two. The diameter of the ash had a non-normal distribution, but the other three sets were normal. However, a nonparameteric test was chosen for all sets so that they would be consistent, A Mann Whitney two-sample U test was used to compare the derived height and diameter growth of those trees treated versus trees with no second year treatment.

Results and Discussion

Survival

June 2004

During June 2004, the first round of survival monitoring took place. The results are summarized in Tables 10 and 11.

Significant results were found for the Shumard oaks for the Terra-Sorb and the mulch fabric treatments. The Terra-Sorb treatment had highly significant results (x^2=11.4216, p=0.0007). The mulch fabric yielded significant results (x^2=4.4635, p=0.0103), but the number of dead (63) was very high so it seems that the mulch fabric contributed a very negative effect to the survival of the Shumard oaks. No significant results were found on any of the green ash treatments.

November 2004

See Tables 12 and 13 for results. Again, No significant results were found in any of the green ash plots. In the Shumard oak plots, highly significant results were found in the TerraSorb® (x^2=13.7011, p= 0.0002) and the DRiWATER® (x^2=7.8936, p=0.0050) plots. The results for TerraSorb® can be interpreted as positive, considering the high number of 'alive' (58) compared to the control group (40). However, the DRiWATER® results can be interpreted as negative, the number of 'alive' being 29. Therefore the application of TerraSorb® to Shumard oaks is likely to contribute to increased survival up to the second year.

Summer 2005

During June-July 2005, the third round of survival monitoring took place. Again, no significant results were found in any of the green ash plots. In the Shumard oak plots, highly significant results were found once again in the TerraSorb® plot (X^2=17.2429, p < 0.0001). The results for TerraSorb® can be interpreted as positive, considering the high number of 'alive' (46) compared to the control group (20). None of the other plots had significant results for the treatments. See Tables 14 and 15 for a summary of results.

Fall 2005

No significant results were found in any green ash plots. In the Shumard oak plots, highly significant results were found in the TerraSorb® plot (X^2=20.8305, p<0.0001). The mulch fabric plot had significant results (x^2=4.9445, p=0.0262). These results can be interpreted as negative, as there were 9 trees alive in this plot, compared to 17 alive in the control plot. See Tables 16 and 17 for results. See Figures 7 and 8 for the progress of survival through the entire two-year monitoring period.

Discussion

In general, the Shumard oaks suffered a steady increase in mortality throughout the course of the study. Overall survival for the oaks stood at 19% at the end of the second growing season. Three of the plots (mycorrhizae, DRiWATER®, and mulch fabric) show survival lower than that of the control group. While the treatment effect is one possible explanation for the higher mortality, it is likely that other environmental factors are involved. One is that deer appear to browse on the oaks, while the ash does not seem to be preferred by deer. Many deer tracks were visible in the oaks plots during 2004, and the trees suffered herbivore damage. Another factor is soil moisture. Shumard oaks are generally intolerant of flooded conditions (Sullivan 1993). Due to the high amount of rainfall in 2004 and early 2005, the soil was very saturated at the study site. Several of the plots were under standing water from November until March; these were located toward the western half of the site (Oak-Mulch and Ash-DRiWATER®).

Comparison of the raw number of trees alive, dead, and not found presents mixed results. After the first year, overall confirmed survival was 205 for the oaks. This is down from 227 in January, yielding a difference of 22. For the green ash, the total number confirmed alive actually rose from 432 in June to 454 in November. Closer inspection of the change in raw numbers yields some apparent inconsistencies. This can be attributed to several factors. Regarding the green ash, this is likely due to the fact that more were actually found in the field during November. The vegetation at the field site is quite thick areas, making location of flags or trees difficult. In November, much of the vegetation has died back, but the trees are mostly green. Also, the flag may have been carried away by wind or an animal, or is completely obscured by the vegetation. Another trend is the high occurrence of trees not found, which may result from several factors: The tree died and has decomposed; or, the tree has died and was carried away by wind, water, or an animal. The surrounding vegetation (often Johnson grass, giant ragweed, poison ivy and goldenrod) is thick and obscures the flag or the tree. It is likely that the survival results from the first round of survival monitoring in June 2004 are artificially low due to errors committed by the volunteers. This is especially evident in the Shumard oak mulch treatment. Other plots likely affected by this include the control, Terra-Sorb, mycorrhizae, and DRiWATER® treatements of the green ash. Placement of the aluminum identification tags on the trees greatly improved the ability to find and keep track of the trees. If the total came up short for a plot, a more focused search could be undertaken in the thick vegetation. However, tags would often disappear or have bite marks on them. This is likely the activity of deer or coyotes, which may be attracted by the shiny reflection.

Another example shows a large and improbable jump in survival for the mulch treatment for the oaks. In many cases, deciding whether the tree is alive or dead is a judgment call. Near the end of the growing season, all of the leaves may have fallen off of a particular living tree earlier than the other trees in the plot. Conversely, a tree may have just died and all of its leaves have fallen off, but it is still pliable. So in this case, this inconsistency most likely can be attributed to error committed by the volunteers recording survival in October 2004.

In spite of the difficulties, the results from November 2004 and afterwards represent much more accurate data from the field.

After the two year duration of the study, 94 Shumard oaks remained alive (19.2%), and 453 green ash survived (90.4%).

Therefore the application of TerraSorb® to Shumard oaks is likely to contribute to increased survival up to the second year. Perhaps the treatments may have been more effective if flooding conditions had not occurred during 2004 and early 2005.

Table 10. June 2004 survival results for Shumard oak

PLOT	TREATMENT	RESULT	RAW NUM.	% SURV	p, α=0.05
1	TerraSorb®	Alive	64	70.3	**p=0.0346**
		Dead	26	28.6	
		Not found	1	1.1	
		Total	91	100	
2	control	Alive	45	45.9	
		Dead	36	36.7	
		Not found	17	17.4	
		Total	98	100	
3	mycorrhizal inoculant	Alive	41	43.6	p=0.3005
		Dead	23	24.5	
		Not found	9	31.9	
		Total	94	100	
4	DRiWATER®	Alive	50	54.3	p=0.5434
		Dead	33	35.9	
		Not found	9	9.8	
		Total	92	100	
5	mulch fabric	Alive	27	28.1	**p=0.0007**
		Dead	63	65.6	
		Not found	6	6.3	
		Total	96	100	

Total survival for Shumard oak: **227 of 471 (48.2%)**

Table 11. June 2004 survival results for green ash

PLOT	TREATMENT	RESULT	RAW NUM.	% SURV	p, α=0.05
6	DRiWATER®	Alive	81	87.1	p=0.3442
		Dead	8	8.6	
		Not found	4	4.3	
		Total	93	100	
7	mulch fabric	Alive	101	96.2	p=0.5973
		Dead	4	3.8	
		Not found	0	0	
		Total	105	100	
8	mycorrhizal inoculant	Alive	77	85.6	p=0.8376
		Dead	5	5.6	
		Not found	8	8.8	
		Total	90	100	
9	control	Alive	88	90.7	
		Dead	5	5.2	
		Not found	4	4.1	
		Total	97	100	
10	TerraSorb®	Alive	85	87.6	p=0.1010
		Dead	1	1.1	
		Not found	11	11.3	
		Total	97	100	

Total survival for green ash: **432 of 482 (90%)**.

*Indicates log-likelihood test (G-test) was employed rather than chi-square.

Table 12. November 2004 survival results for Shumard oak

PLOT	TREATMENT	RESULT	RAW NUM.	% SURV	p, α=0.05
1	TerraSorb®	Alive	58	64.4	**p=0.0002**
		Dead	14	15.6	
		Not found	18	20.0	
		Total	90	100	
2	control	Alive	41	42.7	
		Dead	38	39.6	
		Not found	17	17.7	
		Total	96	100	
3	mycorrhizal inoculant	Alive	25	27.5	p=0.8335
		Dead	25	27.5	
		Not found	41	45.0	
		Total	91	100	
4	DRiWATER®	Alive	29	30.9	**p=0.0050**
		Dead	65	69.1	
		Not found	0	0	
		Total	94	100	
5	mulch fabric	Alive	52	54.7	p=0.4933
		Dead	39	41.1	
		Not found	4	4.2	
		Total	95	100	

Total survival for Shumard oak: **205 of 461 (44.4%)**

Table 13. November 2004 survival results for green ash

PLOT	TREATMENT	RESULT	RAW NUM.	% SURV	p, α=0.05
6	DRiWATER®	Alive	86	90.5	*p=0.1009
		Dead	1	1.1	
		Not found	8	8.4	
		Total	95	100	
7	mulch fabric	Alive	97	94.2	*p=0.8945
		Dead	5	4.9	
		Not found	1	0.9	
		Total	103	100	
8	mycorrhizal inoculant	Alive	91	89.2	*p=0.7202
		Dead	4	3.9	
		Not found	7	6.9	
		Total	102	100	
9	control	Alive	89	93.7	
		Dead	5	5.3	
		Not found	1	1.0	
		Total	95	100	
10	TerraSorb®	Alive	91	91.9	*p=0.0879
		Dead	1	1.0	
		Not found	7	7.0	
		Total	99	100	

Total survival for green ash: **454 of 494 (91.9%)**.

*Indicates log-likelihood test (G-test) was employed rather than chi-square.

Table 14. Summer 2005 survival results for Shumard oak

PLOT	TREATMENT	RESULT	RAW NUM.	% SURV	p, α=0.05
1	TerraSorb®	Alive	46	47.4	**p<0.0001**
		Dead	29	29.9	
		Not found	22	22.7	
		Total	97	100.0	
2	control	Alive	20	20.4	
		Dead	53	54.1	
		Not found	25	25.5	
		Total	98	100.0	
3	mycorrhizal inoculant	Alive	12	12.2	p=0.7204
		Dead	37	37.8	
		Not found	49	50.0	
		Total	98	100.0	
4	DRiWATER®	Alive	18	18.4	p=0.1823
		Dead	78	79.6	
		Not found	2	2.0	
		Total	98	100.0	
5	mulch fabric	Alive	14	14.4	p=0.0643
		Dead	76	78.4	
		Not found	7	7.2	
		Total	97	100.0	

Total survival for Shumard oak: **110 of 488 (22.5%)**

Table 15. Summer 2005 survival results for green ash

PLOT	TREATMENT	RESULT	RAW NUM.	% SURV	p, α=0.05
6	DRiWATER®	Alive	86	87.8	*p=0.9499
		Dead	4	4.1	
		Not found	8	8.1	
		Total	98	100	
7	mulch fabric	Alive	97	93.3	*p=0.9174
		Dead	4	3.8	
		Not found	3	2.9	
		Total	104	100	
8	mycorrhizal inoculant	Alive	91	89.2	*p=0.9878
		Dead	4	3.9	
		Not found	7	6.7	
		Total	102	100	
9	control	Alive	90	93.8	
		Dead	4	4.2	
		Not found	2	2.0	
		Total	96	100	
10	TerraSorb®	Alive	91	90.1	*p=0.4097
		Dead	2	1.9	
		Not found	8	7.9	
		Total	101	100	

Total survival for green ash: **455 of 501 (90.8%)**.

*Indicates log-likelihood test (G-test) was employed rather than chi-square.

Table 16. Fall 2005 survival results for Shumard oak

PLOT	TREATMENT	RESULT	RAW NUM.	% SURV	p, α=0.05
1	TerraSorb®	Alive	45	45.9	**p<0.0001**
		Dead	31	31.6	
		Not found	22	22.4	
		Total	98		
2	control	Alive	17	17.2	
		Dead	58	58.6	
		Not found	24	24.2	
		Total	99		
3	mycorrhizal inoculant	Alive	8	8.2	p=0.4522
		Dead	39	39.8	
		Not found	51	52.0	
		Total	98		
4	DRiWATER®	Alive	15	15.3	p=0.2414
		Dead	81	82.7	
		Not found	2*	2.0	
		Total	98		
5	mulch fabric	Alive	9	9.2	**p=0.0262**
		Dead	81	83.5	
		Not found	7	7.2	
		Total	97		

Total survival for Shumard oak: **94 of 490 (19.2%)**

Table 17. Fall 2005 survival results for green ash

PLOT	TREATMENT	RESULT	RAW NUM.	% SURV	p, α=0.05
6	DRiWATER®	Alive	84	85.8	p=0.4697*
		Dead	6	61.2	
		Not found	8	8.2	
		Total	98		
7	mulch fabric	Alive	97	93.3	p=0.9174*
		Dead	4	3.8	
		Not found	3	2.9	
		Total	104		
8	mycorrhizal inoculant	Alive	91	89.2	p=0.9878*
		Dead	4	3.9	
		Not found	7	6.9	
		Total	102		
9	control	Alive	90	93.8	
		Dead	4	4.2	
		Not found	2	2.1	
		Total	96		
10	TerraSorb®	Alive	91	90.1	p=0.4097*
		Dead	2	1.9	
		Not found	8	7.9	
		Total	101		

Total survival for green ash: **453 of 501 (90.4%)**.

*Indicates log-likelihood test (G-test) was employed rather than chi-square.

Table 18. Shumard oak survival summary, number of trees alive

Treatment	Mar-04	Jun-04	Nov-04	Jun-05	Nov-05
TerraSorb®	98	64	58	46	45
control	99	45	41	20	17
mycorrhizae	98	41	25	12	8
DRiWATER®	98	50	29	18	15
mulch fabric	97	27	52	14	9

Figure 7. Progress of Shumard oak survival

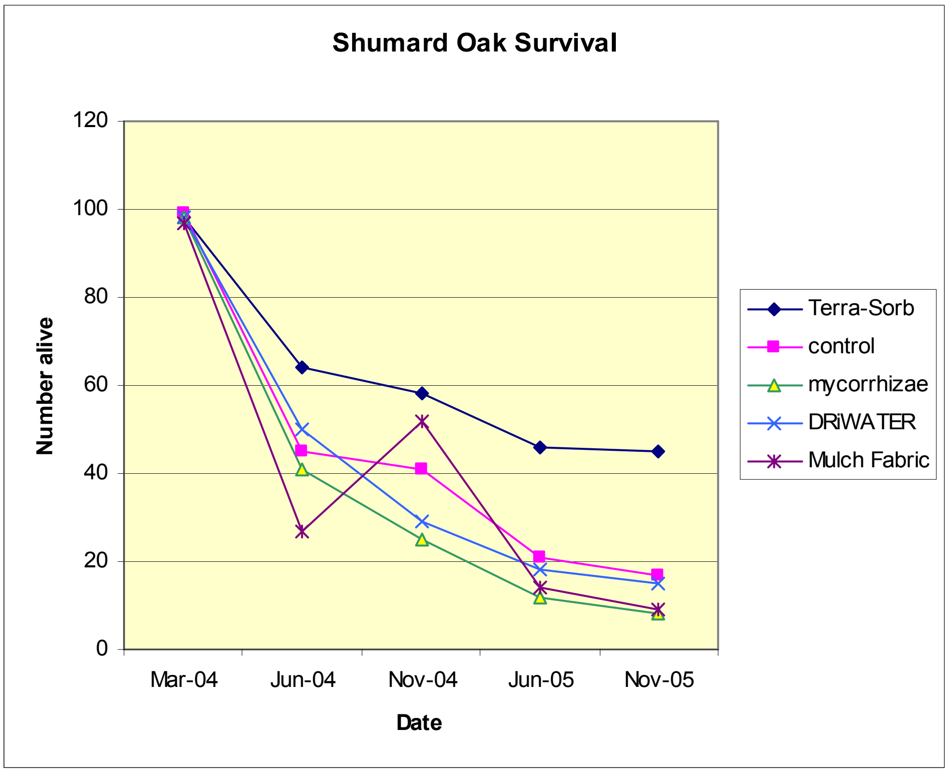
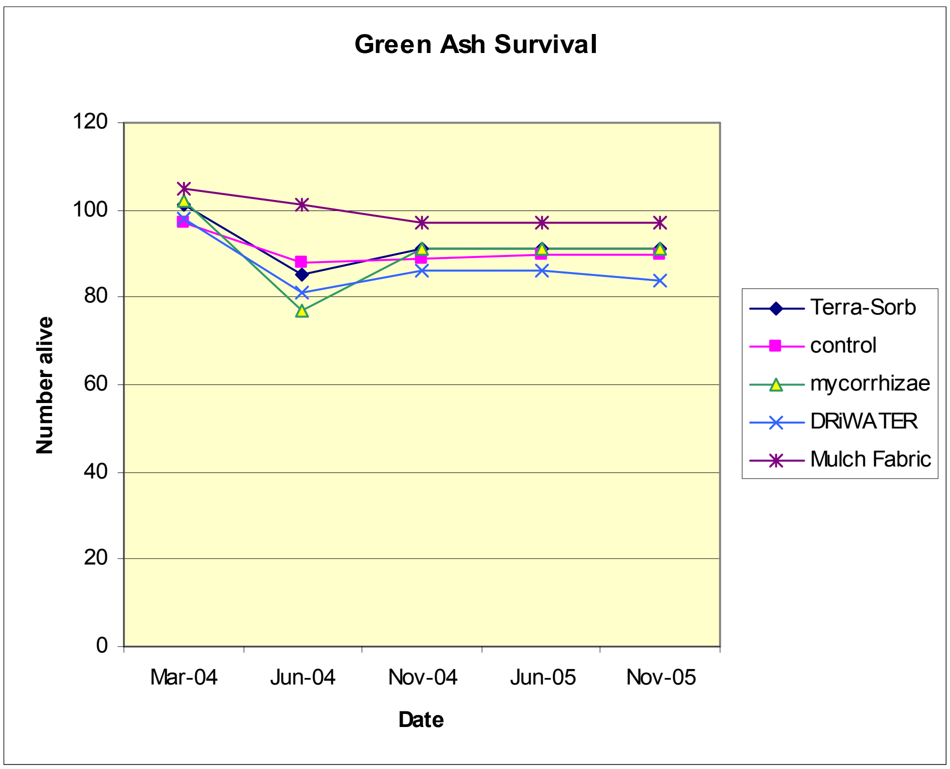


Table 19. Green ash survival summary, number of trees alive

Treatment	Mar-04	Jun-04	Nov-04	Jun-05	Nov-05
TerraSorb®	101	85	91	91	91
control	97	88	89	90	90
mycorrhizae	102	77	91	91	91
DRiWATER®	98	81	86	86	84
mulch fabric	105	101	97	97	97

Figure 8. Progress of green ash survival



Growth

Results

Height and diameter of each tree at year one was measured in January 2005, after one season of growth. Height and growth at year two was measured in January 2006, after two seasons of growth. To see if differences exist, the height and diameter measurements of each treatment are compared to the control. Since it was not possible to conduct baseline measurements of the trees when they were planted, this approach allows a way to assess growth after both the first and second years of growth.

Values for five-number summaries for height and diameter of both tree species are presented in Tables 20-23. A graphical comparison of five-number summaries for the trees by each year is presented in Figures 9-16. Subtracting the year one values from the year two values reveals the growth in height and diameter. The maximum height gain in any one tree was a green ash with the mulch treatment that grew 65.3 centimeters between year one and year two. The maximum diameter growth was 12.25 millimeters, seen with a green ash in the TerraSorb® plot. Overall, the mean increase in height for all ash between year one and year two was 19.9 centimeters. The mean increase in diameter for all ash was 3.03 millimeters.

Shumard oaks do not grow as fast as green ash, and that is reflected in the measurements. The greatest increase in height was 9 centimeters, seen in the DRiWATER® plot. The greatest gain in diameter was an oak that grew 2.20 millimeters in the TerraSorb® plot. The mean increase in height for all of the oaks combined between year one and year two was 2.69 centimeters. The mean gain in diameter for all oaks is 0.50 millimeters.

For the oaks significant results of the Kruskal-Wallis test were in the mycorrhizal inoculant and mulch plots. Diameter of Shumard oaks were highly significantly different among four treatments and the control after one year of growth (Kruskal-Wallis one-way multisample test, $p = 0.0005$). Tukey's Multiple Comparison Test ($\alpha = 0.05$) shows that the ranked values of the mulch and mycorrhizae treatments are higher than the control. Table 24 summarizes the results of the Kruskal-Wallis test and Tukey's MCT for the Shumard oaks.

Many significant results were found in all treatments for the green ash (see Table 25). Height of green ash at year one was highly significantly different among the treatments (Kruskal-Wallis one-way multisample test, $p < 0.0001$). Tukey's Multiple Comparison Test ($\alpha = 0.05$) shows that the ranked height values of green ash with the mulch treatment is greater than the control. A similar result is seen for year two. Height of green ash at year two was highly significantly different among the treatments (Kruskal-Wallis one-way multisample test, $p < 0.0001$). Tukey's Multiple Comparison Test ($\alpha = 0.05$) shows that the ranked height values of green ash with the mulch treatment at year two is greater than the control.

Some of the other treatments were effective on diameter of green ash. Diameter of green ash at year one was highly significantly different among the treatments (Kruskal-Wallis one-way multisample test, $p < 0.0001$). Tukey's Multiple Comparison Test ($\alpha = 0.05$) shows that the ranked diameters of green ash with the mulch, mycorrhizae, and DRiWATER® treatments is greater than the control. For year two, diameter of green ash was highly significantly different among the treatments (Kruskal-Wallis one-way multisample test, $p < 0.0001$). Tukey's Multiple Comparison Test (α =

0.05) indicated that the ranked diameter of green ash with the mulch and DRiWATER® treatments at year two is greater than the control.

Discussion

The mulch and mycorrhizae treatments had significantly higher median diameter than the control group after one year of growth. This reflects the conditions of the first year. As opposed to the DRiWATER® and TerraSorb® products, these treatments are not specifically designed for water retention. Perhaps no advantage was gained in 2004 for growth in oaks from the water-retention gels because of the heavy precipitation and the low tolerance to flooding. If the mycorrhizae and the mulch were the main causal factor in increasing growth, then it would be through other mechanisms than providing water. Perhaps the weed suppressing properties of the mulch fabric contributed to the increase in diameter.

For the green ash, the mulch fabric was the best performer in terms of growth. Significant results were seen for both height and diameter at both year one and year two. As green ash is already flood-tolerant and a rapid grower, the fabric mulch may have increased the growth by reducing the competitive effect of neighboring vegetation. The moisture-conserving properties of the mulch may have also been a factor, especially in the hot, dry summer of 2005. The mycorrhizal inoculant contributed to diameter growth of green ash in year one but not in year two. If it takes some time for the hyphal network to establish, one would not expect positive results immediately, but rather in subsequent seasons. Perhaps the other ingredients (which include a copolymer gel) in the product contributed to the growth. There is no clear explanation for that result. The DRiWATER® may have also contributed to increased diameter for both year one and year two. As to why the DRiWATER® was significant but TerraSorb® was not is difficult to explain. Certainly during the second summer, the additional soil water would have been a benefit. Additional trials in drier years may reveal additional information regarding the effectiveness of these products for these condtions.

Table 20. Summary statistics for height measurements of Shumard oak at year one and year two. Values of five-number summary are in centimeters

TREATMENT	Yr	n	Max	Q3	Median	Q1	Min
Control	Y1	41	71.0	55.0	48.0	41.0	18.0
	Y2	16	72.2	59.7	50.6	37.9	20.2
DRiWATER®	Y1	33	97.2	51.8	41.4	31.5	21.8
	Y2	15	77.8	49.2	41.8	29.0	23.8
TerraSorb®	Y1	58	82.2	49.2	42.6	31.4	4.9
	Y2	37	72.0	49.6	44.6	36.0	8.3
Mycorrhiza	Y1	29	80.0	53.0	45.6	33.8	5.6
	Y2	8	78.2	57.2	50.2	35.9	25.0
Mulch Fabric	Y1	45	77.8	55.7	48.8	37.6	25.0
	Y2	8	77.0	62.2	45.1	33.8	31.0

Table 21. Summary statistics for diameter measurements of Shumard oak at year one and year two. Values of five-number summary are in millimeters

TREATMENT	Yr	n	Max	Q3	Median	Q1	Min
Control	Y1	43	10.00	7.00	5.95	5.15	2.85
	Y2	16	10.85	8.20	7.10	4.85	4.55
DRiWATER®	Y1	33	12.60	7.20	6.25	5.50	3.20
	Y2	15	12.00	7.90	6.25	5.50	4.65
TerraSorb®	Y1	52	11.90	8.18	6.83	5.10	3.45
	Y2	38	12.40	8.85	7.15	5.70	3.75
Mycorrhiza	Y1	27	15.85	10.65	8.20	6.10	3.35
	Y2	9	13.35	8.70	7.10	5.55	2.30
Mulch Fabric	Y1	45	14.05	10.10	6.90	6.05	2.95
	Y2	8	14.65	10.05	6.70	6.48	4.60

Table 22. Summary statistics for height measurements of green ash at year one and year two. Values of five-number summary are in centimeters

TREATMENT	Yr	n	Max	Q3	Median	Q1	Min
Control	Y1	91	92.0	73.0	62.8	53.8	35.0
	Y2	90	121.4	95.4	83.5	64.4	38.8
DRiWATER®	Y1	84	128.6	74.3	62.1	51.1	30.0
	Y2	85	153.6	98.0	84.1	74.7	44.0
TerraSorb®	Y1	88	109.6	68.9	59.1	50.6	17.2
	Y2	87	132.8	99.2	83.5	63.4	28.8
Mycorrhiza	Y1	85	126.4	69.4	59.6	52.4	32.0
	Y2	85	147.2	90.2	71.2	60.6	39.9
Mulch Fabric	Y1	91	134.0	92.7	73.8	60.0	35.2
	Y2	90	158.2	118.7	100.3	79.1	50.6

Table 23. Summary statistics for diameter measurements of green ash at year one and year two. Values of five-number summary are in millimeters

TREATMENT	Yr	n	Max	Q3	Median	Q1	Min
Control	Y1	88	22.65	13.80	11.90	10.35	3.80
	Y2	90	22.90	17.25	15.40	13.30	4.20
DRiWATER®	Y1	84	26.10	15.78	13.58	11.48	6.75
	Y2	85	30.85	20.85	17.35	14.45	8.20
TerraSorb®	Y1	86	20.75	12.90	11.10	8.90	2.95
	Y2	87	26.50	17.05	13.55	10.55	4.95
Mycorrhiza	Y1	71	32.95	17.75	14.05	11.60	7.00
	Y2	84	34.00	19.28	15.68	13.35	7.75
MulchFabric	Y1	88	30.10	21.20	18.73	13.43	7.80
	Y2	90	37.30	25.15	21.08	17.60	10.65

Figure 9: Kruskal-Wallis test for oak height at Year 1

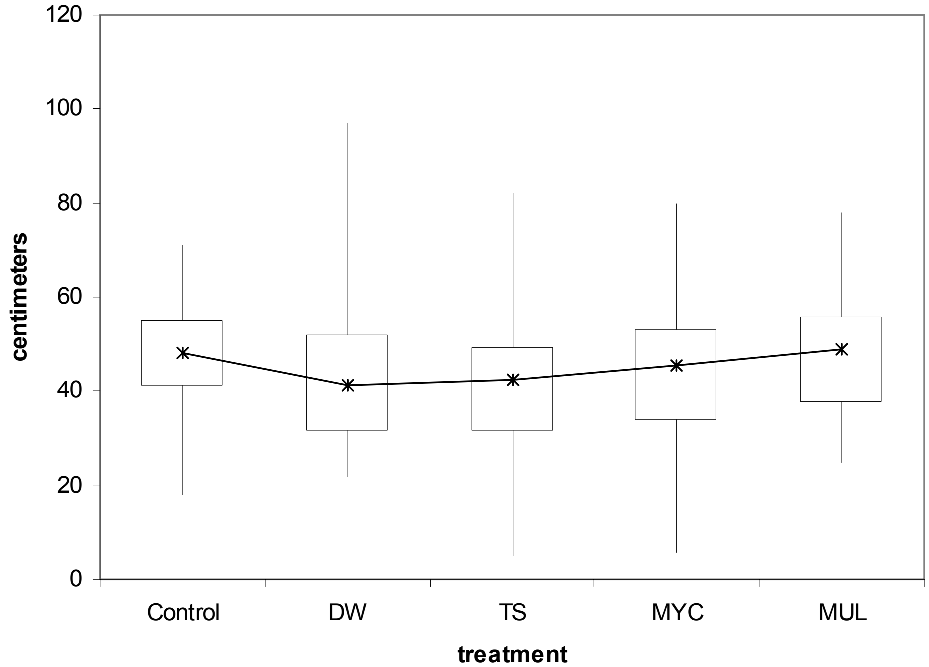


Figure 10: Kruskal-Wallis results for oak height at Year 2

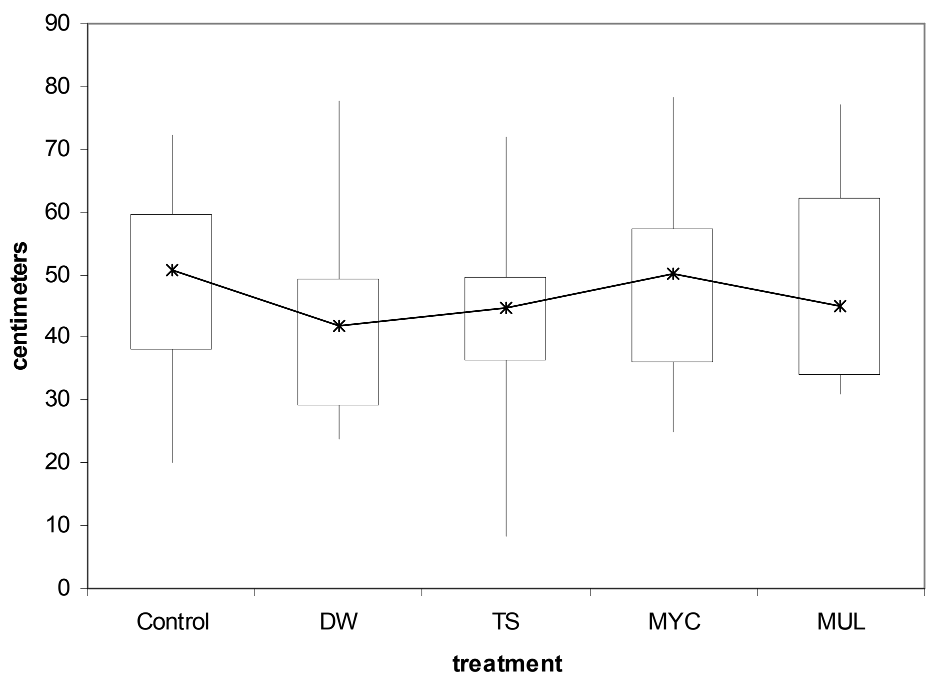


Figure 11: Kruskal-Wallis test for oak diameter Year 1

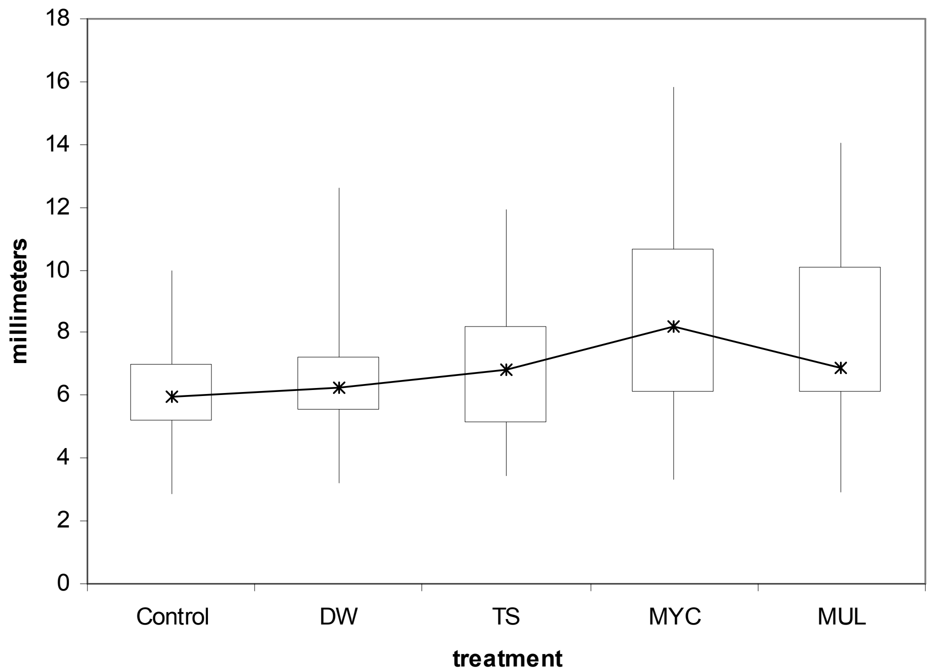


Figure 12: Kruskal-Wallis test for oak diameter Year 2

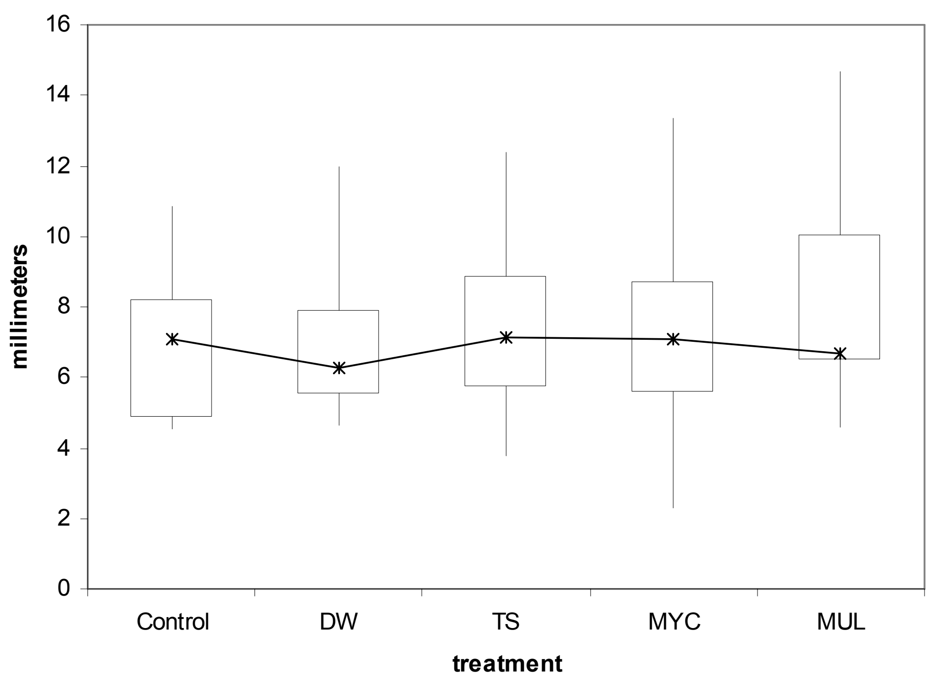


Figure 13: Kruskal-Wallis test for ash height Year 1

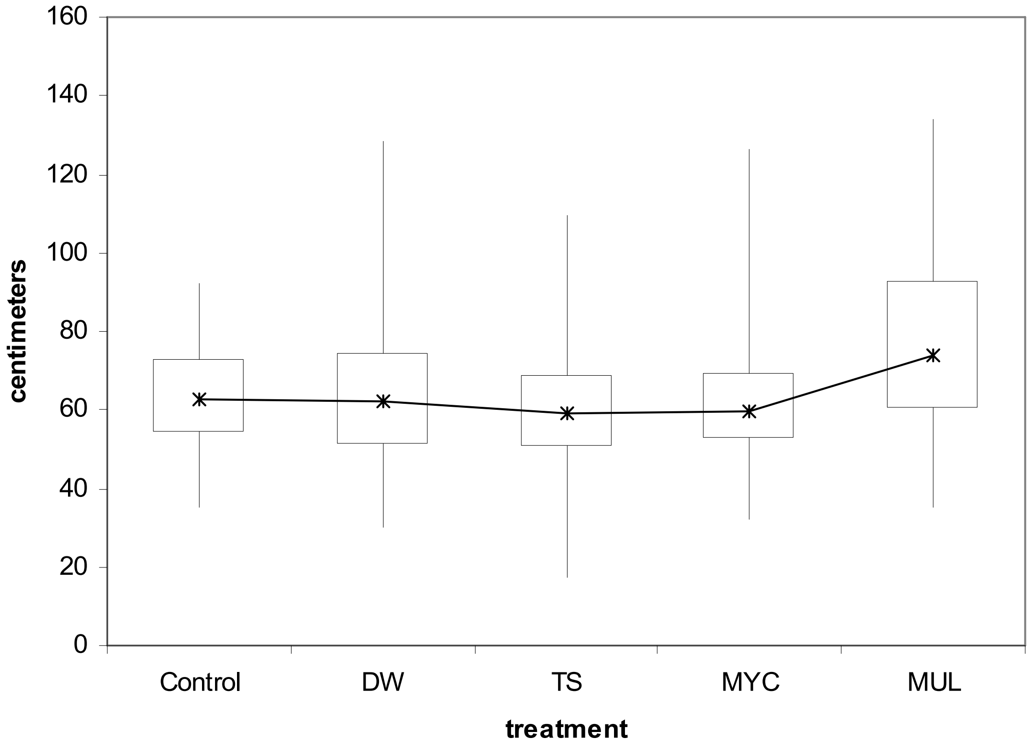


Figure 14: Kruskal-Wallis test for ash height Year 2

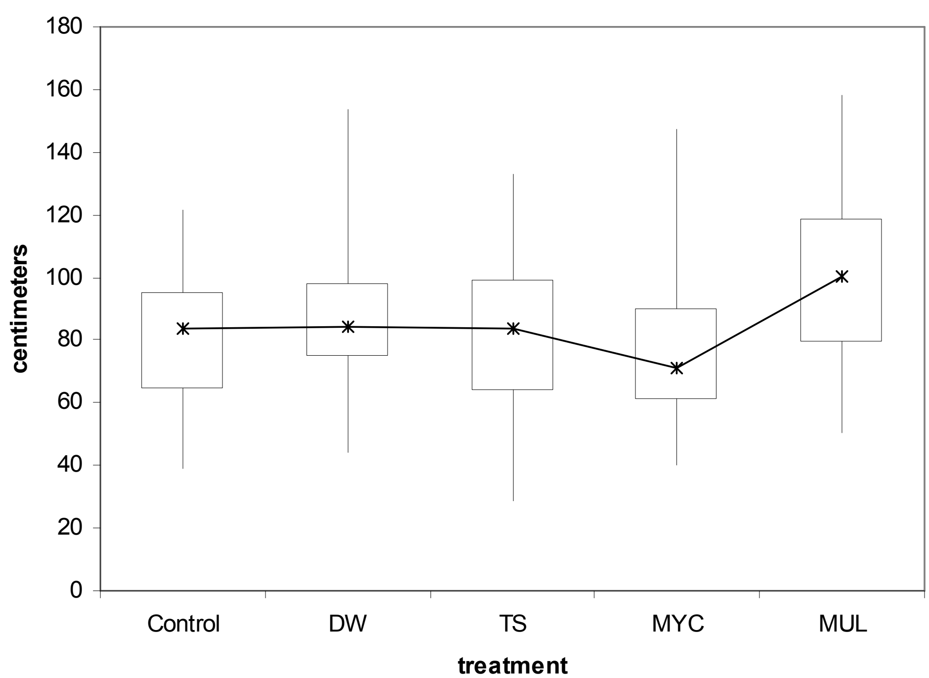


Figure 15: Kruskal-Wallis test for ash diameter Year 1

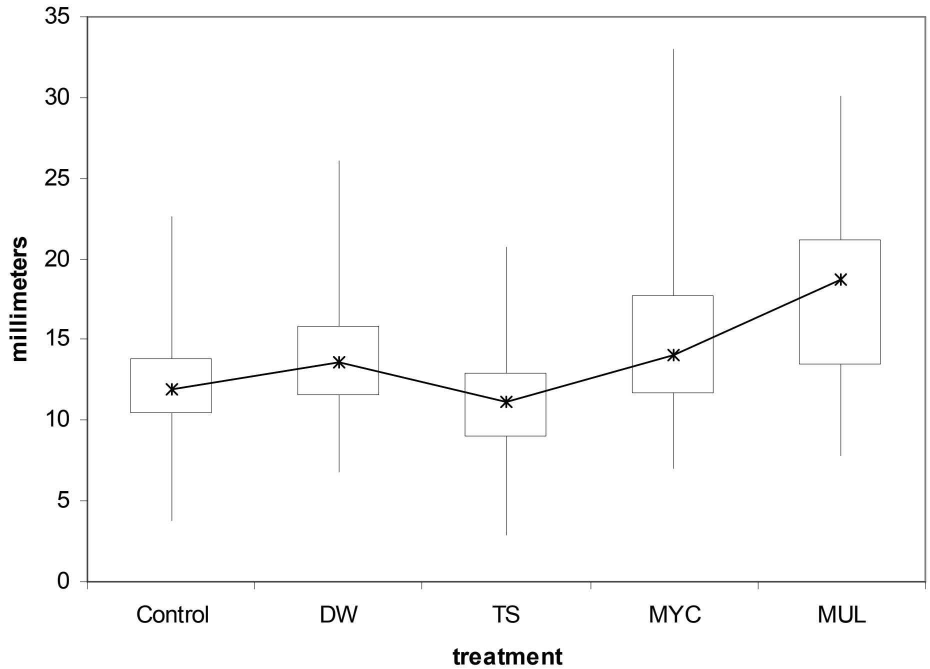


Figure 16: Kruskal-Wallis test for ash diameter Year 2

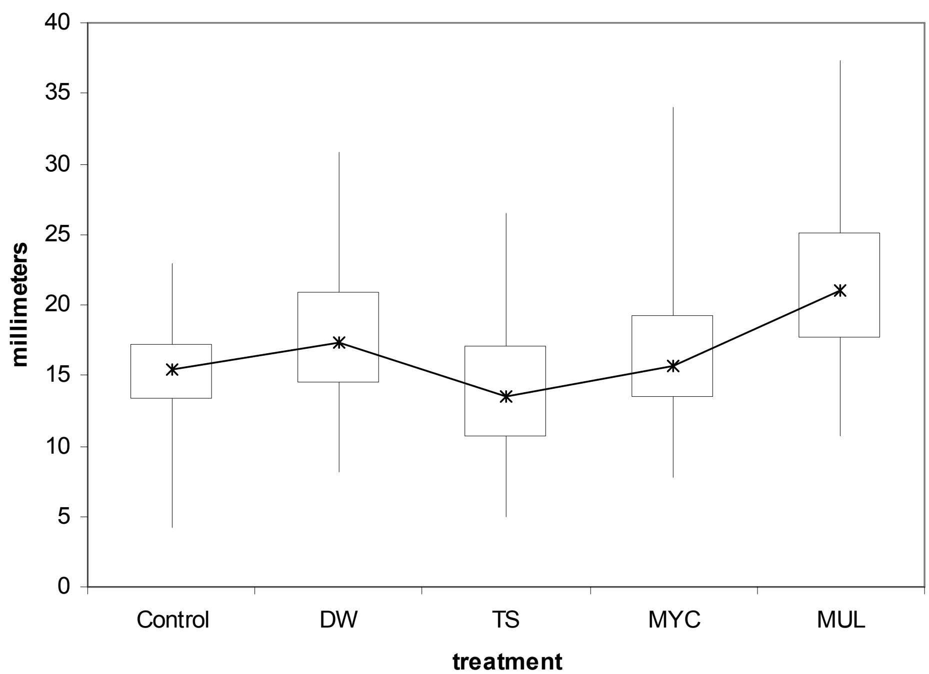


Table 24. Results of Kruskal-Wallis test for growth measurements of Shumard oaks at year one and year two with Tukey's Multiple Comparison Test (α = 0.05) for significant results

	RESULT
Height Y1	p=0.0747
Height Y2	p=0.6084
Diameter Y1	p=0.0005 Control=DRiWATER®=TerraSorb®<Mycorrhizae=Mulch
Diameter Y2	p=0.9340

Table 25. Results of Kruskal-Wallis test for growth measurements of green ash at year one and year two with Tukey's Multiple Comparison Test (α = 0.05) for significant results

	RESULT
Height Y1	p<0.0001 Control=DRiWATER®=TerraSorb®=Mycorrhizae<Mulch
Height Y2	p<0.0001 Control=DRiWATER®=TerraSorb®=Mycorrhizae<Mulch
Diameter Y1	p<0.0001 Control=Terrasorb®<Mycorrhizae=DRiWATER®=Mulch
Diameter Y2	p<0.0001 Control=DRiWATER®=Terrasorb®<Mycorrhizae=Mulch

DRiWATER® Application for Year Two

Results and Discussion

None of the green ash trees died during the time period between the first application of gel pacs in May to the second application during August; therefore, no statistical analysis was done (see Table 26). Thirty-one Shumard oaks were alive at the time of the first gel pac application in May. By August, thirteen of the oaks that had received no treatment had died. None of the oaks that had received the gel pac treatment died (see Table 26). The recording of alive or dead for this aspect of the

DRiWATER® study occurred at the time of the first and second applications of DRiWATER® during 2005, and may not correspond with the numbers taken during the overall survival monitoring for the whole study. The hypothesis that survival of the Shumard oaks is contingent on an application of the DRiWATER® gel pacs was tested using a log-likelihood (G-test) test. The results show a highly significant probability that survival to mid-summer is contingent upon a second-year application of DRiWATER® in hot and dry conditions. (Likelihood ratio $X^2 = 18.466$, $p < .0001$).

Final survival status of the second-year DRiWATER® treatment was recorded in October 2005, at the time of survival monitoring for the whole study. For the green ash, again none that received the second-year DRiWATER® application had died. Only one green ash that received no treatment had died so again no analysis was performed (see Table 28). The total number of ash in the fall count is one higher than in the summer because one tree was not found during that time, but it was located in the fall. For the Shumard oaks that received a second-year treatment, nine remained alive and three had died. Of the trees that did not receive an application in year two, the numbers remained the same with six alive and thirteen dead (see Table 29). Using the log-likelihood (G-test) test, the results for Shumard oaks show a significant probability that survival through the fall is contingent upon a second-year application of DRiWATER® in hot and dry conditions. (Likelihood ratio $X^2 = 5.748$, $p = .017$).

Table 26. Summer 2005 survival results for second-year application of DRiWATER® to green ash (n=84)

	Alive	Dead
Received gel pac	39	0
No gel pac	45	0

Table 27. Summer 2005 survival results for second-year application of DRiWATER® to Shumard oaks (n=31)

	Alive	Dead
Received gel pac	12	0
No gel pac	6	13

Table 28. Fall 2005 survival results for second-year application of DRiWATER® to green ash (n=85)

	Alive	Dead
Received gel pac	38	0
No gel pac	46	1

Table 29. Fall 2005 survival results for second-year application of DRiWATER® to Shumard oaks (n=31)

	Alive	Dead
Received gel pac	9	3
No gel pac	6	13

The second-year application of DRiWATER® apparently had some effect on growth measurements of height and diameter. Summary statistics of growth measurements by treatment are presented in Table 30. No siginificant results were found for the oaks. For the green ash, no significance was found with height, but significant results were found for diameter (see Table 31 and Figures 17-20; * indicates significant results). The median diameter of the treated trees was 3.45 millimeters, while the median diameter of trees that did not receive the treatment was 3.98 millimeters. The diameter of green ash was significantly greater among trees that received a second-year treatment of DRiWATER® than trees that did not (Mann Whitney U test, p = 0.007).

Table 30. Summary statistics for second year treatment of DRiWATER® to assess effect on growth of green ash and Shumard oak. In this case, growth was a derived variable obtained by subtracting height and diameter of year 1 from year 2

	n	Max	Q3	Median	Q1	Min
Ash-Diam-no gel pac	48	11.20	3.98	2.68	1.40	0.35
Ash-Diam-rec gel pac* (mm)	37	9.45	4.55	3.45	2.60	0.35
Ash-Height- no gel pac	46	49.4	27.8	19.8	13.6	6.2
Ash-Height-rec gel pac (cm)	38	43.7	29.5	23.5	17.4	1.4
Oak-Diam- no gel pac	5	0.70	0.60	0.50	0.35	0.05
Oak-Diam-rec gel pac (mm)	9	1.60	0.80	0.50	0.10	0.00
Oak-Height- no gel pac	5	9.0	7.8	1.0	0.5	0.2
Oak-Height-rec gel pac (cm)	9	5.2	2.0	1.6	1.0	0.2

Table 31. Results of Mann Whitney test for assessing treatment versus no treatment effect of second-year DRiWATER® application on growth of green ash and Shumard oak.

	Diameter	Height
Green ash	0.007*	0.1326
Shumard oak	0.4468	0.50

Figure 17. Five-number summary for diameter of green ash for DRiWATER® treatment during year two (n=85).

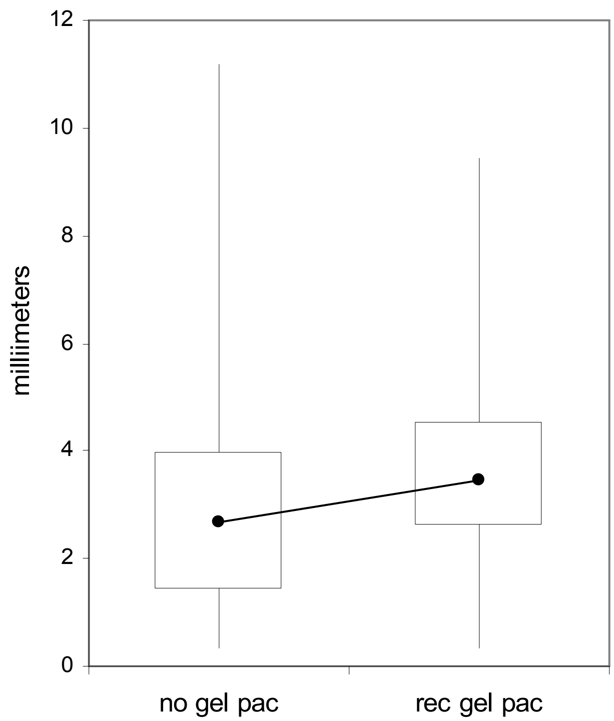


Figure 18. Five-number summary for height of green ash for DRiWATER® treatment during year two (n=84)

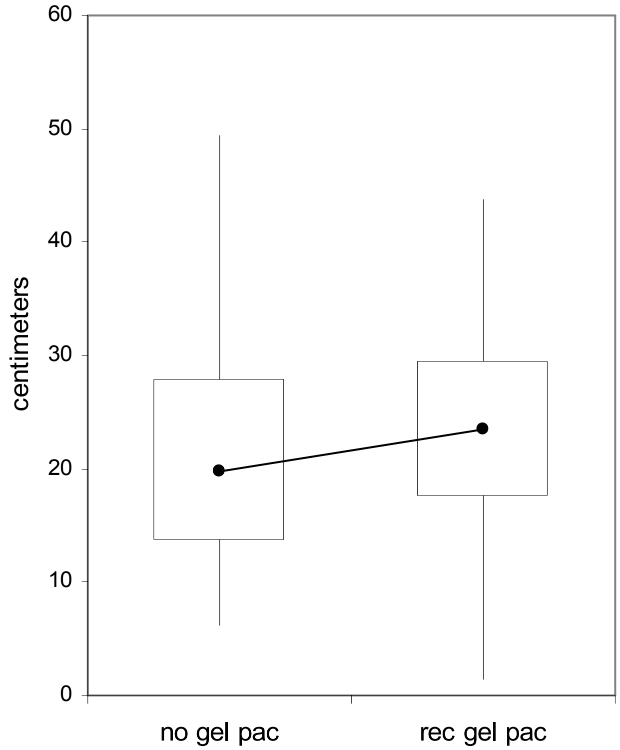


Figure 19. Five-number summary for diameter of Shumard oak receiving DRiWATER® treatment during year two (n=14)

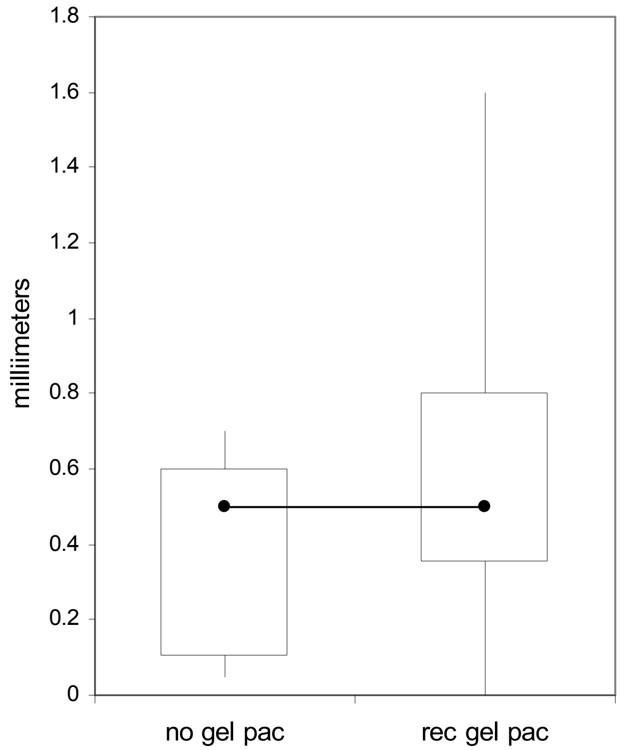
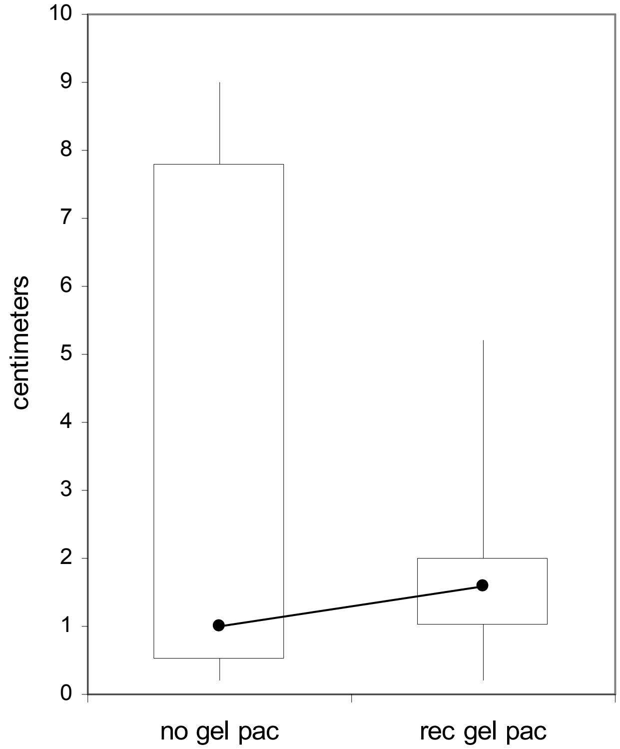


Figure 20. Five-number summary for height of Shumard oak receiving DRiWATER® treatment during year two (n=14)



Climate

Climate is one of the major factors that determine the distribution of species. Amount and timing of rainfall, temperature extremes, amount of frost-free days per year, and frequency and intensity of disturbance events of winds, floods, droughts, hailstorms, and wildfires shape the patterns of vegetation. Species must be adapted to survive. Since this project is primarily concerned with performance under drought conditions, the weather has been an influential factor in the survival and growth of these trees. Texas is characterized as a land of extreme weather, and the two-year period of this study may be one of the best examples of these conditions.

2004

The year started out wet and mild. The last official freeze occurred February 16th, about 3 weeks before the trees were planted. The summer of 2004 was very unusual in terms of weather behavior. In general, the summer was much cooler and wetter than a typical north Texas summer. A series of thunderstorms dominated the month of June, making it the second wettest June since records have been taken in the area (since 1898). At Dallas-Fort Worth (DFW) International Airport, there were 18 days of measurable rainfall. Rainfall in the Denton area exceeded 11 inches for the month. Many of the storms were severe, with high winds and flooding. June also was the 12th coolest average high temperature on record. July began as a dry month, but two consecutive days of rain set new daily rainfall records for two of the last four days of the month. July 2004 is now the 14th wettest July on record. Another unusual phenomenon occurred this summer—the temperature only reached 100° F once; this occurred on July 16. Again in August, cooler temperatures and rainfall were the norm. August 2004 tied 1940 as the 9th coolest August on record (National Weather Service 2006). Significant thunderstorms and rainfall were observed in the north central Texas area.

Ultimately, the summer of 2004 turned out to be the wettest summer on record, and the 17th coolest summer since 1898. The total rainfall for the year 2004 measured at DFW Airport was 47.57 inches (1208.3 mm), 12.84 inches (326.1 mm) above normal. This makes 2004 the 5th wettest year on record (National Weather Service 2006). At Lewisville Lake the annual rainfall measured 51.20 inches (1300.5 mm) (USACE 2006).

2005

The year started out with temperatures above average in January and February as measured at DFW International Airport. March temperatures were slightly below average, and April and May were slightly above average. Precipitation measured at DFW airport was 2.43 inches (61.7 mm) above average in January, and then below average from February to May. The high amounts of rainfall in late 2004 and early 2005 left the field conditions very wet for several months. Several of the plots remained under standing water from November through March. These plots were at the western edge of the site, and include the DRiWATER® and fabric mulch plots for both species. The standing water was mostly gone by April, but the soil remained moist through May.

In contrast to the cool and wet summer of 2004, the summer of 2005 was a typical hot and dry Texas summer. Temperatures were above average for the months of June through September. Precipitation was 2.09 inches (53.1 mm) below average in June, and 1.38 inches (mm) below average in July. August had above average precipitation, but that was due to a 2.46 inch (mm) rainfall August 14^{th}-15^{th}. September was very hot and dry. The average temperature for the month was 6.2 degrees Fahrenheit above normal. The average maximum temperature for September, 95.2° F (35.1° C), sets the record as the warmest value to date. Precipitation in September was 1.06 inches below the normal value of 2.42 inches (National Weather Service 2006). Very dry soil conditions persisted, and drought severity indices show that north central Texas was in a moderate to severe drought. The fall months were unseasonably warm, and the drought only worsened. Record high temperatures occurred each month through December. In November and December high winds, low humidity, and dry fuels made conditions perfect for wildfires. Indeed some destructive wildfires occurred throughout north Texas during December and January, as the dry conditions persisted into the new year. The total rainfall for the year 2006 for Lewisville Lake and DFW Airport was 18.44 (468.4 mm) inches and 18.97 inches (481.8 mm), respectively (USACE 2006, National Weather Service 2006). This is well below the annual average of 34.7 inches (881.4 mm) for DFW Airport.

The monthly and annual rainfall for 2004 and 2005 at Lewisville Lake and DFW Airport is summarized in Tables 32 and 33. DFW Airport is approximately 12.2 miles (19.6 km) SSW of the tree-planting site at LLELA.

Tables 32 and 33. Monthly rainfall (in inches) measured at Dallas/Fort Worth International Airport and at Lewisville Lake, 2004-2005 (National Weather Service 2006; USACE 2006)

Table 32: 2004

MONTH	LEWISVILLE	DFW
Jan	2.51	3.04
Feb	4.09	3.84
Mar	3.20	1.71
Apr	4.56	2.96
May	2.25	4.73
Jun	9.17	10.49
Jul	6.23	4.16
Aug	4.49	4.24
Sept	2.23	1.02
Oct	4.32	5.72
Nov	7.53	5.01
Dec	0.62	0.65
Total 2004	**51.20**	**47.57**

Table 33: 2005

MONTH	LEWISVILLE	DFW
Jan	4.33	4.33
Feb	1.52	1.62
Mar	3.97	2.17
Apr	0.15	0.56
May	3.17	3.35
Jun	1.28	1.14
Jul	0.65	0.74
Aug	2.81	2.46
Sept	0.21	1.36
Oct	0.02	0.89
Nov	0.10	0.02
Dec	0.23	0.33
Total 2005	**18.44**	**18.97**

Discussion of Seedling Establishment Study

The application of DRiWATER® during the second year has some positive effects, both for survival and for growth. Since the green ash trees are hardy and tolerant of extremes in soil moisture, survival in drought conditions was not compromised. Since the Shumard oaks are less flood-tolerant and given the extremes of weather in 2004 and 2005, survival was more of a concern. Despite the flooded conditions of 2004, the summer of 2005 was hot and dry. Significant results among the oaks indicate that the second-year DRiWATER® treatment contributed to their increased survival.

Conversely, there were no significant results of growth for second-year DRiWATER® treatment among oaks, but there were for ash. Shumard oak is a slow-growing species, especially compared to green ash. In general, height growth of trees is believed to take place over a relatively short period of the growing season, and is reliant on stored carbohydrates rather than current photosynthesis. On the other hand, diameter growth mostly depends on current photosynthesis. This growth takes place during a much longer period of the growing season, rendering it more subject to environmental stresses (Kozlowski 1962). Perhaps the increased moisture available to the ash during the hot summer helped the trees ameliorate this stress and contribute to this additional growth in diameter.

Despite the lack of positive results with the mycorrhizal incoculant, this does not necessarily mean that the product is ineffective. A short-term project may not be able to demonstrate much in the way of significant benefit. It may take several years, as the hyphae have to grow out to bring in water, phosphorus, and other nutrients to benefit the plant. Growth is not a very effective measure of inoculant performance. Better assessments of a mycorrhizal colonization include imporoved plant diversity at a site, improved soil structure, greater seedling survival, improved root growth, increase in native vegetation, and reduced weed growth (St. John 2000). Also, this product was just one out of many on the market. Further research with more sophisticated testing of mycorrhizal response as well as long term monitoring s warranted to demonstrate its effectiveness.

The results of the analyses must be interpreted with consideration to the other factors that affected survival and growth. The weather was probably the main confounding factor. The project spanned a period of extremes in the weather—a year of flooding followed by a year of drought. Flooding in late 2004-early 2005 took place mainly during dormant season. This can be less harmful to may species, such as ash. Oaks are still sensitive to flooding regardless. Perhaps if 2004 had not been so wet, survival of Shumard oak may have had greater survival. The negative results seen in oak survival from November 2004 with the DRiWATER® treatment may indicate that the soil may have been more waterlogged than just from the precipitation alone. For the priduct, the same property that can aid survival in drought conditions may hinder survival in flooded conditions for a flood-intolerant species.

Herbivory is another occurrence that probably had some effect. It was observed more in the oaks, but the ash were probably affected to some degree. A future study should include deer fencing or seedling protector tubes. I looked at pricing for deer fencing to enclose the entire study area, and it was prohibitively expensive. Also this fencing would not excluded smaller mammals such as rodents. The seedling protector tubes are more affordable for a project of this scale, and they may also prevent herbivory from rabbits and rodents.

Other factors may have affected survival and growth and complicated the results. Competition from other vegetation was almost certainly a factor, particularly from aggressive species such as Johnsongrass and giant ragweed. Shading from more aggressive plants may have affected Shumard oak, since it is shade-intolerant. On a similar note, allelopathy may have inhibited growth of the trees. Allelopathic properties have been demonstrated in Johnsongrass.

The experimental design of the study could have been strengthened by randomizing the treatments. Microtopographical features like soil moisture and drainage are heterogeneous across the study site. This confounding factor could have been lessened by randomization; however, the coordination of applying the correct treatment during the tree planting would have been logistically challenging considering that this work was done by volunteers.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS: IMPLICATIONS FOR ECOLOGICAL RESTORATION

Objectives

While the tree planting project was not an actual restoration, the intent was to determine if these techniques are valuable to restoration projects in this type of landscape. The ultimate objective for the site at LLELA is an ecologically-based restoration of the land. This is in accordance with the mandates of the U. S. Army Corps of Engineers and the LLELA Consortium (USACE 2007; LLELA 2004). A comprehensive restoration plan is the starting point to undertake this process.

The primary task is to pose the question ‘What type of conditions will the site be restored to?’ The standard approach in restoration ecology has been to determine the historic landscape or pre-disturbance conditions to the fullest extent possible. Often, it is not possible to return to historic conditions—the changes have been too profound. Also, there is no single point in history that can be set for defining a ‘historic’ landscape. Ecosystems have always been changing due to climatic cycles, human impact, and other factors. There are now challenges to the idea that steady-state communities have ever existed for North American forests (Oliver and Larson 1996).

Today, the LLELA site is an old-field in the early stages of succession. The species found on the site match those found in many old-field succession studies. At this stage the site does not have high value for wildlife habitat, potential to attract threatened or endangered species, recreation, or even beauty. Perhaps in fifty or one-hundred years this could develop. But with a little guidance, the site could reach its potential for greater value much sooner. Many restorationists are now relating succession to restoration (Whisenant 1999; Galatowitsch and van der Walk 1998; Young and others 2001; Packard 1994; Betz and Becker 1996). The challenge for restorationist is to figure out the complicated task of ‘directing’ succession.

In the case of the LLELA site, the most appropriate conditions within the constraints of the disturbances that have taken place will determine the ecological trajectory. The soil, hydrology, and vegetation community analyses will be the main framework to decide the most appropriate type of ecosystem for this bottomland site. Whether the site in pre-settlement times was forested or open prairie or meadow is difficult to determine. The assessment of the site suggests it would have been bottomland hardwood forest or wet prairie or some patchwork of both. Due to changes in flood regime from construction of the dam, soil fertility and soil structure changes from agriculture, and other unforeseen factors, the target ecosystem must be able to function under these changed conditions. Perhaps either of these ecosystems would be appropriate. The choice may then be at the discretion of the manager. Other restoration issues that can be considered are specific to the LLELA site. These include contiguousness with other restoration projects, nutrient flux, and desired wildlife habitat endpoints. Educational, recreational, and future research opportunities are also important considerations.

Reference Sites

A reference site serves as a model ecosystem for the design, planning, and assessment of a restoration project. Using historic ecosystems as reference sites must be approached with caution, for reasons already stated. However, if a suitable reference site (historic or current) can be located it can provide data or specimens to contribute to the knowledge base of the restoration project. Suitability could mean high biodiversity, high wildlife value, or a relatively undisturbed history. Features like plant community structure, species composition, and ecological processes can be evaluated. It can help clearly define goals for the project, and success criteria can be formulated (Egan and Howell 2001).

One possible candidate for a reference bottomland hardwood forest ecosystem for the LLELA site is at the Lake Ray Roberts Greenbelt. Barry and Kroll (2003) found a forest stand there to be a relatively intact late-successional forest dominated by the *Celtis-Ulmus-Fraxinus* association. Due to having similar soil series (Ovan clay), proximity to the Elm Fork and similar vegetation, it is plausible that that the LLELA site contains potential to restore to these conditions. One issue with this choice is that the flood frequency at the Greenbelt site is frequently flooded, while the LLELA site is occasionally flooded. Alternatively, a site may be located at LLELA. This forest association may still be appropriate for the LLELA site, due to its typical occurence on first bottom terraces and the trees having a wider range of flood tolerance (Allen and others 2001).

A small number of possibilities exist for a *Spartina*-dominated wet prairie community reference site in north Texas: Hagerman National Wildlife Refuge in

Grayson County (Diggs 2006), Wallace Prairie in Rockwall County, and potential sites in Fannin and Comanche Counties (Diggs and others 1999).

Vegetation community and soil analyses could be done at the reference sites to collect locally specific data. Shannon Diversity and Simpson Dominance indices could be calculated to compare communities. Some of these taxa (e.g. *Spartina*, *Fraxinus*) grow on a wide variety of soils and moisture gradients. But for *Spartina*, since it is relatively uncommon in north Texas, it would be useful to find out what type of conditions it occurs in the region.

One approach to locating reference sites is to examine other landscapes that occur on similar soil types. Ovan clay is found along the Elm Fork of the Trinity in Denton County. It also exists in Dallas, Tarrant, and McClennan Counties. Other vertisol clay soils in north Texas include the Trinity, Kaufman, and Tinn series (Ford and Pauls 1980). Additionally, if restoration projects are planned for other sites on these soils locally, the amendments and techniques suggested here may be applicable.

Also, other areas of LLELA that may be considered for restoration may be on Ovan clay. One such site is directly south of the study site, on the other side of the railroad tracks. It is also an old-field, and has a similar landscape of weeds, young trees, and seedlings.

Ultimately, the leading theories of restoration science urge the restoration of function and process, rather than structure (Whisenant 1999). Principally this concerns the cycling of water, nutrients and energy.

Assessments of a site are vital to define the quality of the location and to determine what measures must be taken to address any deficiencies in functioning. Relevant hydrologic parameters to test could include: depth to water table, drainage, hydraulic conductivity, infiltration, and runoff. Staff gauges, piezometers, and monitoring wells could be installed to collect this data (Whisenant 1999; Allen and others 2001). Soil process health is reflected in parameters such as texture, structure, erosional processes, bulk density (a measure of compaction), soil organic matter, presence of litter, and cation exchange capacity (Whisenant 1999). The levels of nutrients are actually less important. For instance, if nitrogen is low on a site to be restored, it may not be advisable to add fertilizer. The flush of soluble nitrogen could stimulate weed growth. Plus many late-successional species are adapted to conditions of low nitrogen (Whisenant 1999). This follows Odum's criteria for early- and late-successional communities (Odum 1969).

One measure of success of a restored ecosystem is the resilience of the site to the normal periodic stressors that occur locally. Additionally, the restored ecosystem must eventually be self-sustaining to the same degree as the reference site.

Invasive Species Control

Control of invasive plant species is an important duty in ecological restoration. They can interfere with establishment and development of revegetated areas, hindering the project and costing money. Some of these species are not native, and therefore lack natural controls that could keep their population in check. Others are native, but possess aggressive competitive ability. Either way, these species can frustrate revegetation efforts. A species must be judged on its relationship to the ecosystem, not whether it is exotic or native. Some foreign species are harmless, and may fill a niche left by a native species that has declined. An important point to consider when attempting to eliminate an invasive species is to not leave an empty niche. Consider the conditions that allow the invader to establish and thrive.

In the LLELA study area, the most invasive species found are *Sorghum halepense* (Johnsongrass), *Bromus japonicus* (Japanese brome), and *Cardiospermum halicacabum* (balloonvine). Although they are not legally considered noxious, several other species are non-native and may be considered for control: *Torilis arvensis* (hedge parsley), *Phalaris caroliniana* (Canary grass), *Iva annua* (sumpweed) and *Ambrosia trifida* (giant ragweed).

There are several approaches to invasive plant species control: herbicides, prescribed fire, mowing, introducing or restoring grazing animals, soil treatments such as plowing, disking, mulch, soil solarization, as well as combinations of treatments.

Johnsongrass is undoubtedly the most noxious weed found at the study site. Native to the Mediterranean, it is now found worldwide, and is notoriously difficult to eradicate (Diggs and others 1999). In the United States, it is most widespread in the warm, humid southern states (Howard 2004). Johnsongrass is listed as a Category 1 (highly invasive) weed for the southern region by the U.S. Forest Service (USFS 2001). Interestingly, it is not listed as noxious by the Texas Department of Agriculture (Texas Administrative Code 2005). Johnsongrass is a pioneer species that is most common in moist to mesic ecosystems, preferring riparian areas, bottomlands, old-fields, and open disturbed sites such as ditches and roadsides (Howard 2004; Hoagland 2000). In Oklahoma bottomlands and old-fields, it associates with *Ambrosia trifida* (giant ragweed), and in Louisiana bottomlands it associates with *Solidago canadensis* (Canada goldenrod) (Hoagland 2000; Howard 2004). In Louisiana, Johnsongrass is a dominant forb in *Ulmus alata-Ulmus americana-Ulmus crassifolia-Fraxinus pennsylvanica* woodlands (Howard 2004). Johnsongrass is not shade-tolerant and does not persist under closed canopies (Howard 2004).

Johnsongrass produces a prolific amount of seed and develops an extensive rhizome system. These traits allow it to be highly competitive (Howard 2004). Johnsongrass also gains a competitive edge through its robust and rapid growth which quickly shades out other plants (Howard 2004). Also, Johnsongrass exudes allelopathic chemicals, such as *dhurrin*, that have been found to suppress other species (Rice 1984).

While Johnsongrass is despised, it does have some value for wildlife. Deer and rodents graze it, while quail, geese and wild turkey consume the seeds (Howard 2004). It has some value as forage for domestic animals, but under some environmental conditions, it can develop cyanogenetic glycosides that are toxic to livestock (Howard 2004).

Johnsongrass is difficult to control, and many types of efforts are directed toward this end. Some success has been found with certain herbicides. Broadcast foliar sprays of sethoxydim, fluazifop, and haloxyfop have been successful in soybean fields (Banks and Bundschuh 1989). However, the broad application of herbicides is generally not recommended in many restoration projects because desired vegetation may be affected as well.

Innovative techniques have been developed to narrow the application to the target species. The use of a rope wick applicator can improve herbicide applications by its ability to selectively hit these species while using lower amounts of herbicide as well. The wick bar can be mounted on a tractor and set at the desired height. The bar merely wipes the surface of the plant instead of sending a spray into the air that can drift to other plants. Since Johnsongrass quickly surpasses other plants in height, it is easily targeted among other desired species with the wick bar (Dietz 2002). Also, the herbicide does not contact the soil with the use of the wick bar. Success has been reported in agricultural situations with the herbicides glyphosate and sulfosate (Banks and Bunschuh 1989). At LLELA, a small experiment was set up to test the effectiveness of using glyphosate and glufosinate (an organophosphate herbicide) in a wick bar on Johnsongrass. Both herbicides showed significant toxicity to Johnsongrass, but the results overall were better for glyphosate in terms of lower percent cover, lower cost, dilution rate, and lower overall toxicity of the product (Holcomb and others 2003).

In situations of widespread infestation, one practitioner recommends mowing the area when it is actively growing. Then the effectiveness is increased because mowing stimulates new growth and the wick bar will have more contact with the fresh green leaves instead of older senesced material (Dietz 2002). This action also reduces the stored carbohydrate content of the perennial weed (Newman 1993).

Tilling or plowing is another approach to eradicating Johnsongrass. The idea is that this action breaks up the rhizomes, exposing them to the dessicating effects of the sun or killing frosts. But caution must be exercised, since plowing can redistribute and replant pieces of rhizome that can resprout. Also, the process of tilling can disturb the soil which may create a seed bed favorable for germination or bring buried weed seeds to the surface where they can germinate (Howard 2004). Johnsongrass is a heavy seed producer and establishes a seed bank that can remain viable for several years. One estimate shows that seed viability is reduced from 50% to 2% after five to six years in the soil (Newman 1993). Tilling may not be recommended for some wildland restoration sites if other desirable native plants are present.

Prescribed fire is a major component of many ecological restoration and habitat management programs. Fire may promote growth of Johnsongrass. While it is top-killed by fire, it quickly resprouts from the rhizomes (Howard 2004). While very high fire temperatures will kill Johnsongrass seed, most seed is stored deeper in the soil and is protected from heat effects (Howard 2004). In some cases, burning has been shown to increase Johnsongrass cover (Howard 2004). Therefore, prescribed fire is not recommended as a single approach for controlling Johnsongrass.

Solarization is an approach to weed control that employs placing a clear polyethylene sheet over an affected area to use solar heat to kill emerging or existing vegetation. Research shows that solarization of moist soil for seven days kills most Johnsongrass seeds, but is not effective with dry soil (Howard 2004). A solarization study at LLELA early in the growing season was not successful at killing existing plants, but did significantly reduce the emergence of new vegetation (Carr and others 2003).

Fabric mulches are another approach to weed control. While polyethylene sheets completely smother the treated area, mulches are permeable to air and water. Woven fabrics, non-woven mesh, and non-woven spun fabrics were all successful at suppressing Johnsongrass seedlings in one study (Martin and others 1991).

The most effective approach to controlling Johnsongrass appears to be a combination of herbicide, mowing, and tilling treatments (Newman 2007). The main considerations to keep in mind are to prevent the seed from developing and dispersing, to kill seedlings, to kill existing rhizomes, and prevent establishement of new rhizomes (Howard 2004).

Japanese brome (*Bromus japonicus*) is an introduced, cool-season, annual grass. It is found in undisturbed habitats, but is most common on disturbed sites (Howard 1994). It has value for livestock and wildlife for grazing and cover (Howard 1994). However, it is considered a noxious weed on rangeland and wildlands because of competition with native species. Japanese brome only reproduces by seed, and it germinates in the fall (Howard 1994). Typically it is controlled with herbicides such as atrazine (Howard 1994). In general, fire will reduce populations of Japanese brome for a year or two. But the population can re-establish from the seed bank, so a frequent fire regime would be necessary to control the grass (Howard 1994). Mechanical treatments such as mowing may increase Japanese brome populations, so minimizing soil disturbance is recommended (Howard 1994). The best approach to controlling

Japanese brome involves a frequent fire regime, or perhaps a combination of fire and herbicide treatments.

Balloonvine (*Cardiospermum halicacabum*) is a native, annual vine that is common in disturbed areas. It is also cultivated as an ornamental. The vine can grow prolifically and smother native vegetation. It is considered a noxious weed by the Texas Department of Agriculture, and they recommend glyphosate as a control method (Texas Administrative Code 2005). This plant is present at the LLELA study site, but it may not be abundant enough to warrant chemical control.

The use of herbicides in ecological restoration projects is not without risks. The obvious issues of toxicity to non-target plants, animals, and aquatic and soil organisms are complex and will not be addressed here. However, one relevant issue that has emerged lately is the resistance of invasive species to herbicides. As of 1996, 183 herbicide-resistant weed biotypes were identified in 42 countries (Heap 1997). Herbicide resistance in *Sorghum halepense* has been reported since 1991 for several classes of products (Heap 2007). ACCase (Acetyl coenzyme A carboxylase) inhibitors are graminicides that target lipid synthesis (University of Wisconsin 2007). Biotypes resistant to ACCase inhibitors (fluazifop, fenoxaprop, quizalofop, sethoxydim, clethodim) have been reported in Mississippi, Kentucky, Tennessee, Virginia, and Louisiana (Bradley and Hagood 2001; Smeda and others 1997; Heap 2007). ALS (acetolactate synthase) inhibitors are a class of herbicide that affects the amino acid production in plants that leads to protein synthesis in both monocots and dicots (University of Wisconsin 2007). Johnsongrass biotypes have been found in Texas and Indiana to be resistant to herbicides in this class including imazethapyr and nicosulfuron (Heap 2007).

In Mississippi, a biotype of Johnsongrass was found to be resistant to the dinitroaniline pendimethalin. Glyphosate-resistant Johnsongrass was identified in Greece in 1998 (Kintzios and others 1999) and Argentina in 2005 (Heap 2007).

Ultimately the best approach to invasive species control will be based on the unique site-specific factors. Often a combination of treatments is most successful. Also, time of year is critical with treatments such as burning, mowing, and herbicide application. Finally the question must be raised of whether these manipulative methods are necessary, or if processes such as competition or succession will reduce the population of the undesirable vegetation.

Bottomland Hardwood Forest

Government agencies, conservation organizations, and other land managers have been actively carrying out bottomland hardwood forest restoration projects in recent years. The results of these efforts have yielded new information to make plantings more efficient and successful. Characteristics of vegetation and wildlife species have been compiled and analyzed and are available in publications or on the internet to benefit the knowledge base of the practitioner.

There are several types of location where BHF restoration takes place. Agricultural old-fields are probably most common. Mitigation bank sites and mine spoil are also typical (Allen and others 2001).

The most common revegetation technique in bottomland hardwood forest systems is to plant oaks or other mast species. Oaks are by far the most commonly planted species in bottomland forest restoration projects: one survey revealed of practitioners revealed that 78% of the species planted are oaks (King and Keeland 1999). Oaks are heavy-seeded (and therefore have limited natural dispersal), have high wildlife value, are mostly shade-intolerant, and also have economic value as timber (Allen 1997). Other species are expected to establish naturally (Allen 1997; McCoy and others 2002; King and Keeland 1999). This trend is being criticized and the planting of other species such as ash, sugarberry, and sweetgum are encouraged for several reasons. An undisturbed forest on this region naturally has high species diversity. Wildlife such as birds and mammals depend on this diversity (Daniel and Fleet 1999).

Evaluations of revegetation projects revealed that expecting natural invasion not a reliable process (Allen 1997). Natural establishment of seeds from bottomland forest species is affected by availability of seed sources, heaviness of the seed, orientation of mature stand, distance from mature stand, and prevailing winds, with distance being the main factor in dispersal (Allen and others 1988; McCoy and others 2002). While woody invaders have been found up to 640 meters from the nearest mature forest edge, reliable establishment generally does not take place past about 60 meters (McCoy and others 2002; Allen 1997).

There are a number of planning considerations regarding planting oaks and other trees. Initial site preparation can involve various activities such as soil preparation, mowing, prescribed burning, herbicide treatment, fertilizing, and even hydrological restoration. The choice of which activities to employ will be based on soil type, site history, degree of disturbance, and restoration objectives. There are several methods of planting trees: direct seeding, bare-root seedlings, container stock, planting cuttings, transplanting wild stock, and topsoiling.

Soil preparation activities such as disking are used to break up soil compaction and turn over vegetation to add organic matter. In some cases, no soil treatment is necessary or advantageous. Some research has shown that the while the disturbance from disking can enhance survival of some planted trees; it can result in lower natural establishment rates of other species (Allen and others 1988; McCoy and others 2002).

Hydrology must be considered as a factor in bottomland forest restoration projects. Flooding is the major driver in the bottomland ecosystem, where species are adapted to the flows of water, nutrients, sediments, and disturbance that are characteristic of flooding. However, due to far-reaching alterations of land-use and hydrologic regimes, this is often difficult or impossible. Flood pulses may be altered or absent. Water table levels may have dropped. Neglect of the hydrological influence can result in poor establishment, survival, or diversity in restoration projects (King and Keeland 1999; Allen and others 2001). Extensive reworking of soil and drainage is one approach to restoring hydrology. Another method is to establish a variety of sites within the gradient of wetland types in the restoration area (Stanturf and others 2001). Choice of species planted must consider flood-tolerance levels.

A main advantage of direct seeding of acorns and other large seeds is the relatively low cost. Also, direct seeding has a longer planting window throughout the year than planting seedlings. Another advantage is that tree roots can develop naturally. Bare-root or container stock typically has bent, balled-up, or pruned roots. Planting stock may be acquired from local genotypes; in some cases they may need to be collected by hand if commercial availability is spotty. One drawback of direct seeding is that the freshly germinated seedling is less-stress tolerant that bare-root or container stock (Allen and others 2001). Also, this method of planting is limited to oaks and other large-seeded tree species. Seeding can be done by hand or with mechanical planters, which are usually modified from other agricultural equipment (Allen and others 2001). Viability of seed can be a concern. To determine viability of acorns, the float test can be employed: viable acorns will not float in water (except overcup oak), and the nonviable ones float to the top (Allen and others 2001).

One simple technique to prevent herbivory of emerging oak seedlings planted from acorns is to place a tennis ball can around the seedling (Steigman 2006).

Seedlings are available as bare-root or containerized stock. The main advantage here is that the initial survival and growth may be greater. A greater array of species is commercially available as seedlings. Bare-root seedlings are the most common method of planting bottomland trees (King and Keeland 1999). Some drawbacks of bare-root seedlings are that they are more expensive, and that they require greater care during storage, handling, transporting, and planting. Container-grown stock is more expensive still, but may suffer less transplant shock and moisture loss to roots due to the protective soil (Allen and others 2001).

Several species can be established as cuttings, which are short lengths of young stems. Black willow, sycamore, green ash, and cottonwood can be established successfully with this method (Allen and others 2001).

Some performance due to planting method can be species specific, but it is generally true that bare-root seedlings have higher initial performance. A study comparing direct-seeded versus seedlings of cherrybark (*Quercus pagoda*), Shumard (*Q. shumardii*), Nuttall (*Q. nuttallii*), and water (*Q. nigra*) oaks showed that survival was greater for all species except Shumard oak when planted as a bare-root seedling (Ozalp and others 1988). Height and diameter after five years was greater for all species when planted as a bare-root seedling (Ozalp and others 1988). A study on Vertisol soils in Mississippi showed that Nuttall oak planted as bare-root seedlings had greater height than direct seeded oaks or seedlings interplanted with cottonwoods. Direct-seeded oaks had greater diameter and more biomass that seedlings interplanted with cottonwood (Stanturf and others 2004). Another study in Mississippi found that height and diameter were higher for bare-root seedlings of cherrybark, Nuttall, Shumard, water, and willow (*Q. phellos*) oaks than for direct-seeded trees. Poor growth for the direct-seeded plots is attributed to soil-type and competition from heavy presence of Johsnongrass (*Sorghum halepense*) and goldenrod (*Solidago altissima*) (Allen 1990).

Spacing is a consideration when planting trees. Stocking rates are calculated by foresters mainly to maximize lumber production. Restoration projects will generally require fewer seedlings for a given area than for plantations. Wider spacing and random gaps provide openings for invasion of other species. Stocking rates for bottomland trees such as oaks is generally 300-800 seedlings per acre (USDA 2006). The Natural Resources Conservation Service and the U.S. Fish and Wildlife Service have set a standard spacing at 3.6 x 3.6 meters (12 x12 feet) (Allen and others 2001). This is equal to about 746 trees per hectare (302 per acre). Plantings in neat rows have been the standard practice in the past, and this method is defended because planting in rows is easier with mechanical planters and weed-control and monitoring activities may be easier (Allen 1997). However, it may be desirable to avoid this in restoration projects, and managers are encouraged to try other methods to avoid a plantation appearance. If a mechanical planter is used, it could be driven in an irregular pattern. Broadcast seeders may be used instead of mechanical planters. Leaving unplanted gaps in the planting area will also allow room for light-seeded species to invade (Allen 1997).

Competition is another consideration. As previously mentioned, aggressive weedy species like Johnsongrass can suppress growth of seedlings. These species can appropriate valuable nutrients, moisture, and space from recently planted stock. Losses from competition can significantly affect planting success. Allen concludes that plantings on old-field sites that are most vulnerable to drought stress related to soil conditions also tended to have the thickest growth of weeds, particularly Johnsongrass and goldenrod (Allen 1990). The allelopathic properties of these plants in particular may also be a driving factor. But an interplanting technique may benefit the growth of oaks. One study found that oak height was 23% greater when in the presence of a non-oak species. This may suggest that the faster-growing non-oak species (such as cottonwood) may act as a nurse crop by suppressing the shade-intolerant herbaceous competitors (Kruse and Groninger 2003).

Other factors that can contribute to loss of vigor or death are drought, insects, herbivory, and disease. Dutch elm disease and oak wilt may be the most pressing problems for these BHF ecosystems.

Water is a vital component of most every physiological process in trees. Drought or moisture deficiency in the soil is perhaps the most influential environmental stress for plants (Agrios 1997). Insufficient moisture available to plants can hinder growth, lead to a diseased appearance (smaller leaves with a scorched look, defoliation, and wilting), or kill the plant. Plants stressed by drought are more vulnerable to insects and disease (Agrios 1997). The water deficit affects processes such as photosynthesis, salt absorption, nitrogen metabolism, and reduced turgor pressure in the cells (Kozlowski 1962). Too much water from flooding or poor drainage can also have deleterious effects on plants. Flooding during the growing season can kill annuals in two or three days and can eventually kill trees if they are waterlogged for several weeks (Agrion 1997). Physiologically, the roots begin to decay from lack of oxygen to the root zone. These conditions favor anaerobic bacteria (Agrion 1997). As stated earlier, tree species vary in their tolerance to saturated or flooded conditions. Flooding has been cited as a primary factor for mortality in restoration projects, particularly among oaks (Kruse and Groninger 2003; Barry and others 2004).

Damage from animals is a concern in restoration plantings. In North America, wildlife such as deer, various rodents, rabbits, raccoons, and feral hogs are the main threats to planted trees. Palatable species such as oaks are particularly vulnerable. Protective measures such as deer fencing or seedling protector tubes are one option to ameliorate this problem.

While oaks have been a mainstay of reforestation projects in the southern bottomlands, a greater diversity of species is recommended. For ecological restoration projects, the goal is to restore the structure and function of the landscape, not just the trees. More diversity and a more natural appearance can be established initially by following certain practices. Relying on a monoculture of oaks may be more cost effective, but can have several drawbacks. One, availability of seed or seedlings for oaks can be spotty due to increased demand for such stock (King and Keeland 1999).

Therefore managers have had to revert to other species to afforest an area. Second, many bottomland hardwood forest stands were not historically dominated by oaks, but rather by species such as sweetgum and hackberry (King and Keeland 1999). Third, while many managers rely on natural invasion for other species to establish, the rate for establishment can be slow—up to twenty to fifty years (Allen and others 1988). Diversity in an ecosystem—both species diversity and structural diversity—can enhance ecological functions and improve habitat for wildlife. Research suggests that planting a variety of species can increase plant diversity (Allen and others 1988).

Choice of species in restoration projects is influenced by several factors. Cost, availability of stock, the objectives of the restoration, and the specific site conditions will define the appropriate species for a project. Attention must be given to the location of a site on the topographical gradient. Sites adjacent to a river may call for willow and cottonwood, while sites on a first terrace flat may call for elm, green ash, and hackberry. The soil, aspect, groundwater, and hydrology will all influence the ability of the trees to establish and succeed. Knowledge of flood- and shade-tolerance of each species is critical.

A main objective for many restoration projects is wildlife habitat enhancement. Healthy bottomland hardwood forests have greater diversity of most animal groups than any other neighboring habitat type, primarily due to its plant diversity and variety of food sources (Frentress 1986). In Texas, 273 species of birds, 45 species of mammals, 54 species of reptiles, 31 species of amphibians, and 116 species of fish have been identified in bottomland habitats (Frentress 1986). Oaks are known to provide mast that benefit wild turkey, deer, and waterfowl; while a diverse mixed species forest provides high quality habitat for neotropical migratory birds (Kruse and Groninger 2003). A list of bird species that utilize BHF habitat and have been observed at LLELA is found in Appendix B.

Structural diversity is also an important planning consideration. The ecological functioning of undergrowth is important for bottomland hardwood forest ecosystems. Undergrowth benefits wildlife habitat by creating cover, forage, and nesting sites (Allen and others 2001). The vegetation also adds to the roughness of the forest floor, tempering the erosive effects of floods (Allen and others 2001). Inclusion of this in a project increases its complexity, and very little research exists concerning both the autecology of undergrowth species and the restoration projects that have included an undergrowth component. Inclusion of undergrowth in a restoration project presents a logistic challenge: does one establish these species at the same time as the overstory species, or does one come back after the overstory species have matured to some degree? Many understory species are shade-dependent, so a later planting date or nurse plant may be necessary. Successional restoration projects have taken place on prairies, but this approach to forest restoration is unknown. This is a realm with no easy answers, but may provide numerous future research possibilities.

The LLELA site is feasible for a bottomland hardwood forest as a restoration objective. The soils, hydrology, and vegetation show characteristics that would support this type of ecosystem. Existing tree species include bottomland species such as green ash, sugarberry, American elm, cedar elm, hawthorn, and deciduous holly. Areas surrounding the old-field contain also include these bottomland trees, plus some not on the study site itself such as water oak (*Quercus nigra*), Eve's necklace (*Sophora affinis*), and black willow (*Salix nigra*). The hydrology has changed dramatically since impoundment of Lewisville Lake. The site does not receive flood waters from the Trinity River as it used to. However the heavy clay soil has high available water capacity and slow permeability, so after heavy rains the soil can remain saturated or become waterlogged. Ultimately the species selection would have to reflect the current conditions.

If the manager wanted to establish a bottomland hardwood forest at the LLELA site, species like American elm, green ash, and hackberry would likely thrive. They are already present at the site. Green ash showed high survival in the study. These species also provide wildlife value. Additional plantings of these species could be conducted. Shumard oak may be able to establish, but stocking large numbers is not recommended. Considering the slow soil permeability, it can remain saturated after periods of heavy precipitation. Shumard oak may not be able to tolerate prolonged flooding. Specific sites should be identified for higher microtopographical position. Timing is probably the essential factor. Since seedlings are more vulnerable to mortality from flooding, if heavy rain does not occur during the establishment period, they may have a better chance. The superabsorbent polymers would likely increase the likelihood of survival of transplanted trees. The products would be appropriate for a species such as Shumard oak, but is probably not necessary for a widely tolerant species such as green ash. Concerning ease of use, the TerraSorb® product has the advantage of requiring only an initial application. The DRiWATER® requires some additional maintenance. The product must be replaced every thirty days during the growing season, and must be watered each time the product is applied. In the case of the project at LLELA, bringing enough water for up to 200 trees required several hundred gallons. A Type-7 wildland fire engine with a 120-gallon tank was used to bring water to the site, since it is remote from any pumped water source. Several trips were required to complete the job. I could not use the hose from the engine—pulling it through the plot would have damaged the trees. Therefore I had to fiil buckets and haul them by hand to the individual trees. This made the application of DRiWATER® labor-intensive and time-consuming.

The other products used in the study would likely improve the results of future restoration projects. The mulch improved growth of both the green ash and Shumard oaks in the study. It appeared to suppress weeds in most cases, and probably helped conserve water during hot weather. The mycorrhizal inoculant did contribute to diameter growth for both species the first year. While results were limited in this case, the techniques hold great potential.

Wet Prairie

The alternative to a bottomland forest is a wet prairie. Wet prairie restoration projects are perhaps the most important type of wetland restoration taking place today, and yet it presents many challenges (Galatowitsch and van der Walk 1996). Research on this community and on restoration projects—including *Spartina pectinata*-dominated-wetlands, is sparse. Projects that have been attempted have found that *Spartina* wetlands are difficult to establish, due to the fact that the grass reproduces clonally and seed production is low (Fraser and Kindscher 2005).

The choice of vegetation to establish in a prairie restoration will directly depend on hydrology of the site, and soil texture and drainage (Fraser and Kindscher 2001; Kline 1997). Fertility of the soil is less of a concern, as prairie species establish better on nutrient-deficient soils (Whisenant 1999). Fertile or fertilized soils especially can favor the growth of weeds in the initial stages of the project (Kline 1997; Whisenant 1999). While many wet prairie restorations take place on hydric soils, it is probably not be a requirement. If a soil has slow drainage, seasonal events of shallow water may be adequate for wet prairie establishment (Fraser and Kindscher 2001). Indeed, the typical habitat of *S. pectinata* is subject to this regime by temporary flooding in the spring (Weaver 1960). While *S. pectinata* is largely associated with low and wet areas such as seeps, sloughs, and ditches, its primary habitat is dry prairie areas and high ground such as on roadsides and railroads (Mobberly 1956). While not much experimental data exists for the flood-tolerance of *S. pectinata*, there are some hints at its performance under long-term flooded conditions. Plantings of small plugs of *S. pectinata* in low microtopographical areas showed higher mortality than higher sites or larger-sized plugs in one study (Fraser and Kindscher 2005). In another study *S. pectinata* transplants had the greatest area after four growing seasons in the shallowest water, while the lowest area was found in the deepest water (Fraser and Kindscher 2001). Perhaps longer periods of inundation can lead to higher mortality and less growth in *S. pectinata*.

Susan Galatowitsch states that the vegetation composition of wet prairies is relatively easy to document for planning a restoration project—simply compile a list of species. The zonation of the species to microtopography will develop in time (Galatowitsch and van der Walk 1998). Species that have been identified as components of wet prairie and sedge meadow habitats in the north range of the tallgrass prairie that also occur in north central Texas are presented in Appendix C. As described earlier, a gradient is found within the tallgrass prairie that varies along the soil moisture regime. Areas with more prolonged saturation may be dominated by sedge meadow associates such as *Juncus*, *Carex*, and *Scirpus*. Areas with only intermittent saturation may be dominated by *Spartina pectinata*, with herbaceous associates such as *Eleocharis* and *Carex*. The *Panicum virgatum-Tripsacum dactyloides-Sorghastrum nutans* grassland association will be characteristic of mesic areas.

The appropriate techniques for revegetation will depend on the unique characteristics of the plants. Like any other restoration, the main concerns are site preparation, choice of planting method, and source of plant propagules. For prairies and prairie wetlands site preparation may consist of soil work, treatments for weedy species, and prescribed burning. There are many considerations when deciding whether or not to plow or disk a site. It has the benefits of removing weedy vegetation cover, returning organic matter to the soil, and loosening the soil to provide a receptive texture for seeding. Agricultural old-fields are often good candidates for soil work when they are dominated by annual weeds. Plowing can be concentrated on the densest populations of weeds if other stands of desired vegetation exist on site. Caution must be advised regarding plowing or disking as it is a soil disturbance. Some weed growth can be stimulated by the disturbance (e.g. Johnsongrass) or buried weed seeds can be exposed. It can also cause erosion, especially on slopes. Plowing may not be advised if many desired plants are already extant, especially if they are conservative or rare. Plowing or disking is not recommended near trees in a savanna or woodland, as it may damage the roots (Packard and Ross 1997).

There are several planting methods available to the restorationist for prairie projects. Seeding is a common method; many grasses and forbs reproduce by seed. Other species, such as some sedges and *Spartina pectinata*, are poor seed producers and their rhizomes, tubers, or roots must be dug up and transplanted. Also, smaller amounts of topsoil can be transferred to a restoration site which will inoculate the recipient site with seeds, roots, and mycorrhizal fungi.

Seeds can be sown directly by mechanical methods such as seed drills and hydroseeding, or they can be broadcast by hand. Interseeding is a technique where seeds are dispersed on an unplowed site among existing vegetation, perhaps following a burn. Soil conditions and density and type of existing of vegetation cover will determine the best method.

The major decision about obtaining seed is choosing a source. Many species are available commercially; however, local ecotypes are preferable. Collecting seeds can be done by hand or various types of machines. The collector must know the time of year seed is mature for each species. Collected seed must be processed for storage and sowing. Chaff or fleshy plant parts must be removed. The seeds themselves must be dried. Seeds must be stored at a certain temperature and humidity to retain viability. Some species need treatments such as stratification, scarification, or inoculation with nitrogen-fixing bacteria before propagation (Apfelbaum and others 1997).

In general, *Spartina pectinata* is considered challenging to establish, as it mostly spreads by rhizomes. It can be established by seed, but development is slow (USDA 2006). The few existing studies on establishment of *S. pectinata* reveal some useful information. One study evaluated various sizes of plugs that were transplanted to an old-field. The authors concluded that planting numerous small plugs will help increase the overall area of the grass, while large plugs help establish density (Fraser and Kindscher 2005). Large plugs have the advantages of minimizing transplant shock and transporting the existing seedbank and soil biota along with the plant (Fraser and Kindscher 1999). Another study demonstrated that transplanting with a tree spade is a successful technique in establishing populations of *S. pectinata* and *Eleocharis macrostachya*, a spikerush (Fraser and Kindscher 2001). Despite these successes, the authors conclude that several years, perhaps decades, may be necessary for desired wet prairie species to achieve dominance (Fraser and Kindscher 2001; Fraser and Kindscher 2005).

Galatowitsch recommends a successional approach to revegetation. Essentially there are three stages. Stage 1 plants are those species that can compete with aggressive disturbance colonizers. For a wet prairie this will include big bluestem, switchgrass, prairie cordgrass, and coreopsis (Galatowisch and van der Walk 1998). Stage 2 plants are sown by hand two or three years after the aggressive weeds are reduced. This mix will include grasses and forbs that can establish after a burn. Stage 3 plants are sensitive to competition and attempts to establish should not be attempted early in restoration projects. Also these plants are better established as plugs or transplants rather than seeding (Galatowitsch and van der Walk 1998).

Mycorrhizal fungi are an important component of the prairie community, but their relationships are not well understood in prairie wetlands. Studies have established that many of the Cyperaceae form mycorrhizal associations (Miller and others 1999; Muthukumar and others 2004). Research shows that *Spartina pecitinata* is a host of vesicular-arbuscular mycorrhizae (VAM), specifically *Glomus tenue*, under a variety of soil moisture conditions (Anderson and others 1986). Even though mycorrhizal fungi may exist on a site, they may be a generalist species or a mismatch of fungi and plant host (Miller 1997). Identifying and including the appropriate mycorrhizae in restoration projects may increase the chances of success.

Fire is an important ecological process of prairies; this is no different for prairie wetlands. Prescribed fire will be part of any wet prairie, tallgrass prairie, or savanna management strategy. *Spartina pectinata* readily survives fire due to its deep rhizomes, especially during wet periods (Walkup 1991). A study that examined culm density and aboveground production in *S. pectinata* indicates that fire may increase its competitive advantage and reproductive capability (Johnson and Knapp 1993). Research is scant, but *S. pectinata* may indeed be a fire-dependent species. After restoration projects, a wet prairie can be burned the year following planting (Galatowitsch and van der Walk

1998). While *Spartina pectinata* –dominated wetlands are known for low species diversity, one study suggests that frequent fire in wet prairies results in lower diversity in the plant community.

A major motivation to restore wet prairie is to provide rare habitat for wildlife. Certain birds such as Sedge wren (*Cistothorus platensis*) and the Yellow Rail (*Coturnicops noveboracensis*), require the structure of thick stands of *S. pectinata* for nesting (Fraser and Kindscher 2005). Other birds that rely on wet prairie habitat include King Rail (*Rallus elegans*), Wilson's Phalarope (*Phalaropus tricolor*), Northern Harrier (*Circus cyaneus*), Short-eared Owl (*Asio flammeus*), and American Bitterns (*Botaurus lentiginosus*) (Galatowitsch and van der Walk 1998). All of these species have been observed at LLELA, but most of them occur rarely or uncommonly (Dick and others 2003). Wetlands are also ideal habitat for amphibians and reptiles. If these creatures are in decline, then the birds that prey on them will be affected too. For example, American Bitterns rely heavily on frogs in their diet (Galatowitsch and van der Walk 1998).

A wet prairie restoration could be an appropriate target ecosystem for the study site at LLELA. Although the site is mostly weedy, the vegetation survey indicates that sedge species like *Eleocharis palustris* and *Carex crux-corvi* are present. These plants are both obligate wetland species and are considered conservative. Another sedge, *Carex festucacea*, is conservative facultative wetland species. Although hydric soils were not detected, *Spartina pectinata* can grow on mesic sites as well as moister ones. The soils at the site have a high available water capacity due to slow surface runoff and slow permeability. Based on this, perhaps a *Spartina pectinata-Eleocharis-Carex* plant association is appropriate for wetter sites and a *Panicum-Tripsacum-Sorghastrum* association with *Elymus canadensis* as an associate is appropriate for more mesic sites. Driest sites could receive a *Schizachyrium-Sorghastrum-Andropogon* seed mix. This entire plant community would be maintained by periodic prescribed fire. Detailed information on the natural distribution of *Spartina pecitnata* and other wet prairie communities in north Texas is scant. A search of herbarium records of the southwest revealed that it has been collected from nine counties in north Texas and numerous locations in the Texas Panhandle and Oklahoma (see Figure 21). No herbarium specimen has been found from Denton County. Considering that the soil and hydrological conditions are appropriate and that these species have occurred in the region, the choice of this rare target community is warranted. In north Texas, the *Spartina-Eleocharis-Carex* association has a conservation rank of G2G4, G2 being Globally Imperiled and G4 being Apparently Secure. The *Tripsacum-Panicum-Sorghastrum-Helianthus maximiliani* association is ranked at G1, Globally Critically Imperiled (The Nature Conservancy 2004). The habitat value would be tremendous to the aforementioned birds, as well as amphibians and reptiles which are imperiled in their own right (Stuart and others 2004). This type of ecosystem could also have research and educational value as well, consistent with the mission of LLELA.

A list of wet prairie, sedge meadow, and wet-mesic prairie plant species that are known to occur in north central Texas is found in Appendix C.

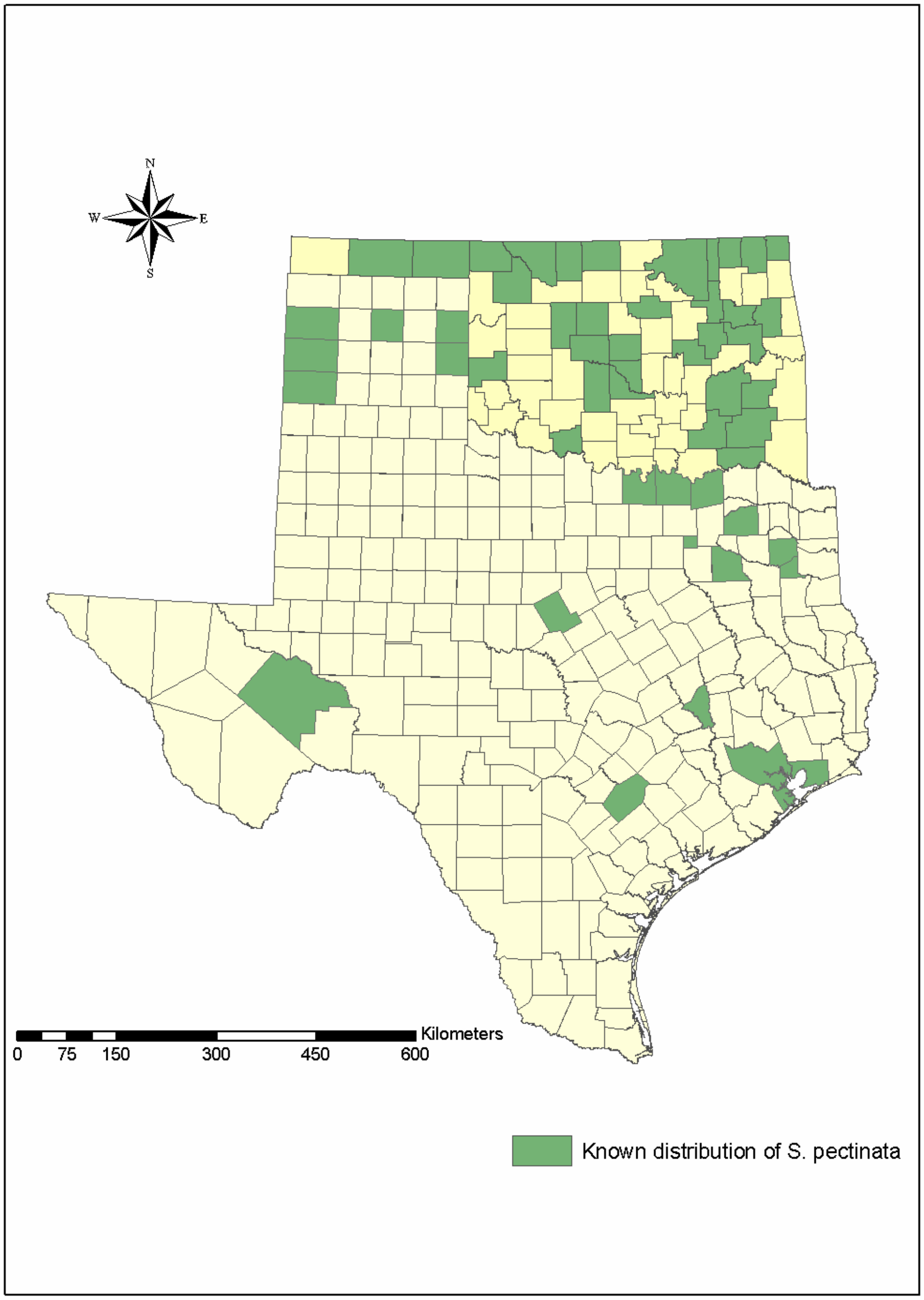
If the manager decides that a wet prairie is the most appropriate target ecosystem, then that person will want to remove the remaining trees at the study site. Most of the surviving trees will be green ash. A tree spade can be utilized to carefully remove the tree and the root ball with minimal damage. The remaining holes can then be filled with plugs with prairie vegetation and soil. The trees can then be used for other revegetation projects.

Prescribed burning would be a periodic management activity for a restored wet prairie. The frequency and timing of burns has several considerations. Reemergence or establishement of native vegetation can be affected by fire frequency. Also, utilization of the site by wildlife will depend on these factors. For example, American Bitterns avoid annually burned areas in North Dakota. A fire regime of two to five years is recommended for management of this species (Dechant and others 1999).

While some hydrologic studies have taken place at LLELA, site-specific research would yield valuable information for guiding the restoration of the study site. Monitoring wells could yield Information such as chemical parameters of groundwater and hydraulic characteristics of the water table and aquifer. This data could be used to calculate a hydrologic budget for the site.

The products used in the tree study at LLELA may have some potential in wet prairie plantings. In addition to its use as a root dip, the polyacrylamide comes as a powder that can also be mixed into soil or used as a coating for seeds. Grasses and most forbs are mycorrhizal, so the technique may be beneficial. This is a topic that has received little attention, and deserves further research.

Figure 21. Known distribution of *Spartina pectinata* by county in Texas and Oklahoma, based on herbarium specimens



Sources: Hoagland and others 2004; VAST 2006; Flora of Texas Database 2006; Botanical Research Institute of Texas (BRIT)

Ultimately, the decision of the target ecosystem for the LLELA site restoration will be at the discretion of the manager. Both bottomland forest and wet prairie may be successful.

If the manager wanted to establish a BHF, species like American elm, green ash, and hackberry would likely do fine. They are already present at the site. Green ash showed high survival in the study. These species also have high wildlife value. Shumard oak may be able to establish, but stocking high numbers is not recommended. The soil permeability is very slow so it can remain saturated during periods of plentiful rainfall. Shumard oak may not be able to tolerate this prolonged flooding. Specific sites could be targeted for higher microtopographical position. Other appropriate species for planting may include: *Morus rubra*, (mulberry), *Crataegus* spp. (hawthorn), *Prunus* spp., (plum), *Xanthoxylum clava-herculis* (prickly ash), and *Acer negundo* (boxelder).

A wet prairie may also be appropriate. Here the objectives may be to establish an endangered plant community and provide rare habitat for wildlife. Long-term management considerations would include a regimen of prescribed fire. The decision rests on which ecosystem best embodies the values of wildlife habitat creation, rare ecosystem preservation, environmental education, recreation (e.g. hiking, birding) and research potential.

Values of Restoration

Use of Volunteers

The act of ecosystem restoration not only provides habitat value to wildlife, but also has values to the human community. For increasingly urbanized people disconnected from nature, it provides a way for them to reclaim their relationship to the land.

The involvement of volunteers is an integral part of countless ecological restoration projects. They provide invaluable free muscle to an endeavor that is labor-intensive and chronically under-funded. There are benefits that reach beyond the scope of the individual project. The participants themselves receive a rewarding experience of the outdoors which has little equal. Volunteers cite a variety of motivations to participate in restoration projects, which provide clues to a greater societal yearning for a meaningful nature experience. The use of volunteers can contribute to a forging, and ultimately a restoration of a sense of community between the public and nature. However a growing tension has emerged in the field of restoration between proponents of volunteer-supported projects and those who favor a more professional development.

William Jordan is a particularly eloquent advocate of using volunteers in restoration projects. It is a way to enhance community, which ultimately increases the value of the project. Millions of people enjoy outdoor pursuits such as gardening, hiking, and bird watching. Jordan's vision is that volunteering in restoration projects will become another form of outdoor recreation, but with a more profound result.

> If we undertake this work (and play) in a spirit of respect, then restoration becomes a way of generating real value. In this way, the community may gradually come to see the ecosystem not only as valuable, but as worth paying for. Having engaged the ecosystem by helping restore it, people

> are going to care about it more than they care about a “natural” ecosystem, which they mat be inclined to take for granted (Jordan 2003).

He lauds that this type of activity will replace “escapist, destructive, and ultimately elitist” outdoor activities with a deeper engagement that will model the relationship between humans and the rest of nature (Jordan 2003).

Philosopher Andrew Light is another proponent of including volunteers in restorations. He echoes Jordan’s refrain that the value is enhanced where projects unite the human and natural communities. His claim is that the practice of ecological restoration contains “inherent democratic potential” by its use of volunteers (Light 2000). Light also is a voice cautioning against the professionalization of restoration ecology due to its possible threat to the use of volunteers. There is a growing tendency in the field toward certification of restoration practitioners. This can range from formalized training in use of pesticides or prescribed fire to formal degree programs at universities. This in itself is not bad, he states, but it is not the solution to every dilemma as some (he claims) have suggested (Harris 1997). One of the dangers of certification of restoration practice is that it would place more restrictive definitions on the elements and practice, thereby restricting the language (Light 2000). Also, certification would establish authority, which can be abused. Additionally, the field would be dominated by a hierarchy of professionals rather than an apprentice-type relationship. This would run contrary to a culture where public participation is encouraged. In Light’s view, all of these trends would stifle public participation and therefore jeopardize the democratic potential of restoration (Light 2000).

Another philosopher, Eric Higgs, is also concerned about the increasing professionalization of restoration practice. He is not wholly opposed to the idea, and does cite some benefits to the trend. But he warns that the movement toward professionalization invites ‘commodification’ of the practice. By this he means that the focus of the practice shifts from things to devices, and that the field becomes more exclusive and efficient. This trend contains the potential to allow corporations to usurp restoration to polish their own (sometimes tarnished) image, with little concern for the actual ecological functioning of the site (Higgs 2003). Corporate-sponsored projects may not report the failures of a project as the scientific community would. A company may consider the information proprietary or may not want to release any information that would reflect negatively on the company’s image (Higgs 2003).

The demand for professional restoration practitioners is increasing. Private sector- and government-sponsored projects are growing due to policies such as ‘no net loss of wetlands’, which encourage restoration through mitigation (which is in itself an example of ‘commodification’). Engineering and environmental consulting firms now hire full-time restoration ecologists. Government agencies favor the consistency guaranteed by a professional firm over a group of amateur volunteers (Higgs 2003). Higgs also illustrates the desire of some persons to make restoration their life’s work. It fulfills the noble aspiration for ‘right livelihood’ that is a rare accomplishment for anyone (Higgs 2003).

Higgs continues Light’s concern for certification by raising some additional points. While certification could improve benefits for clients by promising advanced knowledge, competence, and ensuring a legal liability, it could limit the practice in several ways. It could limit the types of persons who are allowed to practice, as in medicine or engineering. This would lower the role of public participation and therefore lower its value. Certification could also render the practice more uniform. While this may offer a consistent knowledge base, it could limit creative options to problem solving. In addition, certification would alter the political economy to favor the needs of professionals over those of the community. This could lead to higher costs for restoration projects (Higgs 2003).

As stated earlier, Higgs is not opposed to professionalization of restoration; he would like to see an incorporation of high-quality practice with the opportunity for local participation when appropriate. He develops a theme of focal restoration based on the idea of *focal practice*. He takes the idea of focal practice from Albert Borgmann, who posited the *device paradigm*, which suggests that technology is a restrictive force in our lives (Higgs 2003). Focus is removed from meaningful, conscientious activities when we permit ourselves to be distracted by consumption and devices. Focal practice includes activities done with intent that generate meaning in our lives, such as community meals, spontaneous music sessions, or quality time with a child. Higgs applies this idea to restoration, where *focal restoration* is "shaped by engaged relationships between people and ecosystems" (Higgs 2003). He contrasts this with what he terms *technological restoration,* which is connected with the device paradigm and commodifies the practice. The inclusion of volunteers is central to focal restoration: "Participation in restoration encourages focal practice, and the tide of corporatization and efficiency measures, at least as exclusive or dominating forces, is held at bay" (Higgs 2003). Many voices in restoration have called for the uniting of the science of ecology with cultural activities and values. John Cairns proposed "ecosocietal restoration," William Jordan writes of "restoration-as-celebration," and Dennis Martinez suggests "ecocultural restoration" (Higgs 2003).

Another development in the philosophical debate about volunteers in restoration has surfaced recently with William Throop and Rebecca Purdom challenging Eric Higgs's views on participatory restoration. They assert that there is a "participation paradox" when it comes to the restoration of wilderness areas. They cite the U.S. Wilderness Act of 1964, which decrees that land managers shall minimize human impact on these ecosystems. Regardless of the values and benefits achieved, the push for participatory restoration is in conflict when it comes to wilderness areas. The Act states that wilderness is an area "untrammeled" by humans and that "have been affected primarily by nature", and that the footprint of human activity is "substantially unnoticeable." (Throop and Purdom 2006)

Throop and Purdom address the participation paradox by suggesting limits to participatory restoration. They employ a healing metaphor that suggests in these sensitive areas, restoration projects should be left to the professionals and done in the most efficient manner. Restoration is an invasive procedure, like surgery, and the minimum force and equipment should be used (Throop and Purdom 2006).

They also make the claim that Higgs advocates that restoration activity should be designed for the volunteers benefit. Higgs replies that this is not the case; participation is "not an end but rather a means to an end." (Higgs 2006) He adds that participation is not even a necessary component of focal restoration. A professional crew can also practice focal restoration (Higgs 2006).

This argument conjures up the old debate about the exact meaning of the term 'wilderness.' Higgs feels that the term is restrictive and he prefers the term 'wildness.' Many pages have been written on this topic by esteemed figures and it will not be given a full treatment here. In short, there is a pervasive myth about wilderness that finds its roots in the European 'discovery' of the New World. The idea of the Americas a landscape devoid of people (aside from the Noble Savage who lived with no impact on the land) filled with dramatic scenery and virgin forests pervades our literature, schoolbooks, and national character. What has been revealed is that in 1492 there may have been 40 to 100 million people in the Western Hemisphere. For North America, a moderate estimation has been placed at 53.9 million (Denevan 1992). These people built cities, roads, had intensive agricultural practices, altered waterways, and practiced burning of the landscape. The land seemed empty when many settlers arrived because up to ninety percent of this population had died of introduced diseases within one hundred years of first contact (McCann 1999). The generally accepted date of arrival of the Native Americans/First Nations/Amerindians is placed around 12,000 years ago, based largely on Clovis spear points (Ferring 1997). So the landscape of the Americas had at least 115 centuries of some degree of human impact before European arrival, and only perhaps two centuries of minimal human impact before the landscapes began to be widely characterized in prose, poem, painting, and photograph. Of course, not all areas received equal impact at all times. Some areas were very sparsely populated, while other areas saw heavy impact. We have come to define this word wilderness as an area uncultivated and uninhabited by humans. But sometimes the evidence that these landscapes are shaped by humans is right under our noses. The fact that certain species assemblages inhabit a particular area, or that the Great Plains is a prairie and not a forest, could be attributable to the land use practices of these early inhabitants of the Americas.

Ultimately, it seems that both camps raise important issues. In the case of the wilderness debate, on one side are scholars like J. Baird Callicott who want to deconstruct the word wilderness because of its connotations (Callicottt 1994). On the other side are defenders of the concept such as Reed Noss and Dave Foreman, who argue that the passing of the Wilderness Act and other similar legislation have spared large areas of land from the multiple-use butchery (grazing, forestry, mining, recreation) that the other public lands are subject to. While the word wilderness is semantically loaded, it has had a pragmatic value in accomplishing a greater good (Noss 1994; Foreman 1994).

This argument evokes the nature/culture debate. Are humans part of nature? Have the multitudes of modern society become too absorbed by our culture and technology, which leaves them disconnected from their deeper relationship to nature? That is one question that many restorationists are trying to address by trying to actively restore this relationship through volunteer participation in these projects.

Herbert Schroeder is an environmental psychologist with the U. S. Forest Service. He performed a study to determine which values and rewards motivated volunteers in restoration projects. He systematically reviewed newsletters of several restoration groups under the umbrella of the Volunteer Stewardship Network in Illinois, which is coordinated by the Illinois Chapter of the Nature Conservancy (Schroeder 2000). Schroeder emerged with nine central themes of motivations, each with several sub-themes. Volunteers are clearly driven by a sense of purpose to protect and restore features described as nature, native landscapes, or biodiversity. They feel that the current state of nature is threatened. The remnants that are left are isolated and under further pressure from developers and invasive species. The volunteers feel like their contribution can make a difference, ultimately benefiting future generations. The participation in restoration projects brings personal rewards, from being outdoors to seeing real results from their work. Learning and sharing knowledge is also satisfying. Their participation can be exciting and fun. Restoration has social dimensions as well, including socializing and making new friends and developing a sense of community by being part of a group. The volunteers reveal how they are just ordinary, hard-working, and enthusiastic people who are united in their concern for nature. Participation in a restoration project evokes strong feelings toward nature. Many report an affinity or an aesthetic appreciation towards nature, and a particular attachment toward their work site. Finally, many report being inspired by sources such as religion, Native American ideas, and literature. These themes reflect a deep desire for the general public to connect with the natural world, and that participation in restoration projects is an effective vehicle to connect (Schroeder 2000).

LLELA Project

The contribution of volunteers for the tree survival study at LLELA was invaluable. The sheer scale and labor-intensity of the work to be done was enormous.

The initial task of planting the trees was essentially unskilled grunt work. I recruited undergraduates from the laboratory sections of the Environmental Science class for non-science majors at UNT plus a few students from Brookhaven College. While I received free labor, they received a hands-on outdoor educational experience (and extra credit). Their previous outdoor experience presumably varied, and is reflected in comments that ranged from the revelry of getting dirty akin to gardening to the fact that two of the girls had never been camping before. The work of the tree planters was indispensable, but as they are not experienced mistakes could have been made. One does not need a degree in forestry to plant a tree, but there are some procedures to follow to ensure that the tree has the best chance for survival. When planting a bare-root tree one must make sure to not bend the roots. When returning the fill soil it is important to not leave any pockets of air which can desiccate the roots and kill or weaken the tree. The soil at the tree planting site was sticky and difficult to work. The roots must have minimal exposure to air, yet many trees were left laying in the sun for too long. And while these procedures were explained to the volunteers, they may have been just as quickly forgotten. So it is possible that some mortality may be attributable to the planting method and the unskilled nature of the volunteers.

The next phase of the project involved periodic evaluation of survival and collection of growth data. Since this stage required accuracy, greater attention to detail, and some scientific background the volunteers were mostly graduate students plus a few personal friends. For the most part this worked, but there is always potential for human error. When I analyzed the data, some values were clearly wrong and had to be discarded from calculations. There are several scenarios that can explain this. The first example is survival monitoring. The first monitoring event took place in June following the tree planting. Individual identification tags had not yet been placed on the trees, so at that point it was just a count and not a disposition for a uniquely identified tree. This is not really the fault of the volunteers, they undoubtedly worked hard; however, a volunteer is less invested in the project than I am, so they may not put forth the extra effort to find the trees in the field while battling the Texas heat, mosquitoes, itchy head-high vegetation, snakes, chiggers, and poison ivy. Second, I found that some of the growth values on the data sheets were clearly not possible. These plots were typically done in a team of me and one other person. One person would take the measurement and call it out while the other would write it down. Here errors could have been committed in dictating the measurement or in writing it down. The measurement could have been misheard. I noticed that errors occurred more frequently when two people worked together than when I worked by myself. In general, it seems there was a trade-off of accuracy for speed. To ameliorate this, when working in a team extra effort should be made to ensure accuracy. Caution must be taken when unskilled volunteers are used in a project where data collection is a component.

Finally, the use of volunteers for this project made a positive contribution to the dimension of my personal experiences. The whole project was a series of logistical challenges to be met. The recruitment and coordination of the volunteer workers provided many lessons. This served as a kind of training in management and interpersonal skills that I have never received anywhere. This experience may benefit me later in my career, particularly if I pursue a direction in restoration ecology or resource management.

Aesthetics

Aesthetics and beauty have emerged as values that may be a consideration for a restoration project. While it may not have any ecological function, the consideration of aesthetics may benefit a project in several ways. In practical terms, it may prevent a property being lost to developers. Land in degraded or neglected condition may be appealing to developers, since they may be less expensive to obtain. Conservationists and restorationists can form a partnership and acquire the land for repair (Berger 1990). An aesthetically-appealing restored property may be more valuable in the eyes of the community and therefore more likely to be protected.

In the National Environmental Policy Act of 1969, aesthetic concerns are among the assurances that the federal government must provide for the environment (NEPA 1969).

Restoration ecologist James Allen supports the idea of including aesthetics as a consideration for projects. When referring to the tendency for foresters to plant in neat rows, he questions the practice and suggests a more natural-looking pattern: “I am aware of no demonstrated biological justification for planting more randomly, but there should be no reason why aesthetics should not be considered to be an important part of restoration especially on public lands and in cases where it does not add significantly to the cost of the project.” (Allen 1997)

In his land ethic, Aldo Leopold states that “a thing is right when it tends to preserve the integrity, stability, and beauty of the biotic community.” (Leopold 1966) His concept of community was expansive: “The land ethic simply enlarges the boundaries of the community to include soils, waters, plants, and animals, or collectively: the land.”

(Leopold 1966) Regarding the human role in nature, Leopold states, “a land ethic changes the role of *Homo sapiens* from conqueror of the land-community to plain member and citizen of it. It implies respect for his fellow-members, and also respect for the community as such” (Leopold 1966). Ecological restoration can be a powerful force in upholding Leopold’s Land Ethic. The stability and integrity come from the science, beauty can come from a concern for the aesthetic dimension of nature. Community is inherent in ecological restoration; its value can be extended by appropriate inclusion of volunteers.

Ecological restoration presents a new level of opportunity for science. We are faced with a legacy of countless examples of disturbed ecosystems. Years ago, John Cairns articulated the potential that restoration projects have for researching the recovery of damaged sites. It presents a litmus test of our knowledge of the structure and functioning of ecosystems and the mechanisms of succession (Cairns 1987). William Jordan expresses this potential poetically: “…if we replace the Cartesian idea of the experiment as a performative interaction with it, it ceases to be a mere manipulation and the extraction of information becomes a conversation.” (Jordan 2003)

The aims of this thesis are several. One is to contribute to an understanding of the natural history of the region, in this case with a focus on bottomland forests and wet prairies. Ecological restoration projects have many locally specific considerations. Therefore, another goal, perhaps more important, is to inform, facilitate, and participate in restoration efforts in north central Texas.

APPENDIX A

LIST OF PLANT SPECIES OBSERVED AT THE LLELA STUDY SITE

Table 34: List of plant species observed at the LLELA study site

FAMILY	SCIENTIFIC NAME	COMMON NAME	DUR	HABT	NATV	WETL	*C*
Anacardiaceae	*Toxicodendron radicans*	Poison ivy	P	shrub, vine	Y	FAC	1
Apiaceae	*Eryngium hookeri*	Eryngo	A	forb	Y	FACW	2
	Polytaenia nuttallii	Nuttall's prairie parsley	B	forb	Y	-	5
	Torilis arvensis	Hedge parsley	A	forb	N	-	-
Apocynaceae	*Apocynum cannabinum*	dogbane, Indian hemp	P	forb	Y	FAC	3
Aquifoiliaceae	*Ilex decidua*	holly	P	tree, shrub	Y	FAC-	3
Asclepiadaceae	*Asclepias viridis*	Green antelope horns	P	forb	Y	-	3
Asteraceae	*Ambrosia trifida* var. *texana*	Giant ragweed	A	forb	Y	FAC	0
	Aster ericoides	Heath aster	P	forb	Y	FACU-	3
	Aster subulatus	wireweed	A	forb	Y	OBL	0
	Cirsium texanum	Thistle	B/P	forb	Y	-	3
	Dracopis amplexicaulis	Clasping coneflower	A	forb	Y	FAC+	3
	Helianthus annuus	Giant sunflower	A	forb	Y	FAC	0
	Iva annua	Sumpweed	A	forb	Y	FAC	0
	Lactuca serriola	lettuce	A	forb	N	FAC	-
	Packera tampicana	Ragwort	A	forb	Y	FACW+*	1
	Solidago canadensis	Goldenrod	P	forb	Y	FACU+	0
	Vernonia baldwinii	Western ironweed	P	forb	Y	UPL, FACW-*	3
Caprifoliaceae	*Symphoricarpos orbiculatus*	Coralberry	P	shrub	Y	FACU	1
Cupressaceae	*Juniperus virginiana*	Juniper	P	tree	Y	FACU-	2
Cyperaceae	*Carex blanda*	Charming caric sedge	P	graminoid	Y	FAC	-
	Carex crus-corvi	Crow-foot caric sedge	P	graminoid	Y	OBL	5
	Carex festucacea	Fescue-like caric sedge	P	graminoid	Y	FAC, FACW*	6-9
	Eleocharis palustris	Large-spike spike-rush	P	graminoid	Y	OBL	8
Euphorbiaceae	*Chamaesyce* sp.	sandmat	A	forb	Y	-	2
	Croton monanthogynus	Prairie tea	A	forb	Y	-	2
	Euphorbia bicolor	Snow on the prairie	A	forb	Y	-	3
Fabaceae	*Desmodium* sp.	Beggar's ticks	P	forb	Y	-	-
	Gleditsia triacanthos	Honey locust	P	tree	Y	FAC	2
	Lathyrus hirsutus	Rough pea	A	vine,forb	N	-	-
	Melilotus officinalis	Yellow sweetclover	A/B	forb	N	FACU	-
	Neptunia lutea	Yellow neptunia	P	forb	Y	FACU	3
	Prosopis glandulosa	Honey mesquite	P	tree, shrub	Y	FACU-	-

	Vicia sativa	Common vetch	A	forb	N	FAC	-
Lamiaceae	unknown	-	-	-	-	-	-
	Monarda sp.	bee-balm	A/P	forb	Y	-	5
Lythraceae	*Lythrum alatum* var. *lanceolatum*	Lance-leaf loosestrife	P	forb/shrub	Y	OBL	3
Moraceae	*Maclura pomifera*	Bois D'Arc	P	tree	Y	UPL	2
Oleaceae	*Fraxinus pennsylvanica*	Green ash	P	tree	Y	FACW-	5
Onagraceae	*Gaura parviflora*	Velvet-leaf gaura	A	forb	Y	FACU*	2
	Oenothera lacinata	Evening primrose	P	forb	Y	FACU	1
Poaceae	*Bromus japonicus*	Japanese brome	A	grass	N	FACU	-
	Hordeum pusillum	Little barley	A	grass	Y	FACU	0
	Lolium perenne	English rye grass	P	grass	N	FACU	-
	Panicum capillare	Witchgrass	A	grass	Y	FAC	2
	Phalaris caroliniana	Canary grass	A	grass	N	FACW	1
	Sorgum halepense	Johnson grass	P	grass	N	FACU	-
Polygonaceae	*Rumex crispus*	Curly dock	P	forb	N	FACW	-
Rosaceae	*Crataegus sp.*	Hawthorn	P	shrub/tree	Y	-	1
	Prunus rivularis	Creek plum	P	tree	Y	-	2
Rubiaceae	*Galium aparine*	Cleavers	A	forb	Y	FAC-	0
Rutaceae	*Zanthoxylum clava-herculis*	Prickly ash	P	tree, shrub	Y	FAC-	4
Sapindaceae	*Cardiospermum halicacabum*	Balloon vine	A	vine	Y	FAC	2
	Sapindus saponaria	Western soapberry	P	tree, shrub	Y	FACU-	3
Sapotaceae	*Sideroxylon lanuginosum*	Chittamwood	P	tree	Y	FACU	2
Scrophulariaceae	*Agalinis fasciculata*	Rose gerardia	A	forb	Y	FAC	2
Solanaceae	*Physalis longifolia*	Common ground cherry	P	forb	Y	-	2
Ulmaceae	*Celtis laevigata*	Sugar hackberry	P	Tree	Y	FAC	2
	Ulmus alata	Winged elm	P	Tree	Y	FACU	5
	Ulmus americana	American elm	P	Tree	Y	FAC	4
	Ulmus crassifolia	Cedar elm	P	Tree	Y	FAC	2
Viscaceae	*Phoradendron tomentosum*	Mistletoe	P	aerial	Y	-	0

Sources: Diggs and others 1999; Reed 1988; Buckallew 2007

DUR—Duration: A—annual, B—Biennial, P—Perennial
HABT—growth habit
NATV—Native: Y—yes, N—no
WETL—Wetland Indicator Status
C—Conservation coefficient

APPENDIX B

BIRD SPECIES THAT ARE KNOWN TO UTILIZE BOTTOMLAND FOREST AREAS AND HAVE BEEN OBSERVED AT LLELA

Table 35: Bird species that are known to utilize bottomland forest areas and have been observed at LLELA

Wood Duck	*Aix sponsa*
Great Blue Heron	*Ardea herodias*
Great Egret	*Casmerodius albus*
Red-shouldered Hawk	*Buteo lineatus*
Wild Turkey	*Meleagris gallopavo*
Yellow-billed Cuckoo	*Coccyzus americanus*
Barred Owl	*Strix varia*
Ruby-throated Hummingbird	*Archilochus colubris*
Belted Kingfisher	*Ceryle alcyon*
Red-bellied Woodpecker	*Melanerpes carolinus*
Yellow-bellied Sapsucker	*Sphyrapicus varius*
Downy Woodpecker	*Picoides pubescens*
Hairy Woodpecker	*Picoides villosus*
Eastern Wood Peewee	*Contopus virens*
Eastern Phoebe	*Sayornis phoebe*
Great Crested Flycatcher	*Myiarchus crinitus*
White-eyed Vireo	*Vireo griseus*
Warbling Vireo	*Vireo gilvus*
Red-eyed Vireo	*Vireo olivaceus*
Blue Jay	*Cyanocitta cristata*
American Crow	*Corvus brachyrhynchos*
Carolina Chickadee	*Parus carolinensis*
Eastern Tufted Titmouse	*Parus bicolor*
Carolina Wren	*Thryothorus ludovicianus*
Ruby-crowned Kinglet	*Regulus calendula*
Blue-gray Gnatcatcher	*Polioptila caerulea*
Eastern Bluebird	*Sialia sialis*
Hermit Thrush	*Catharus guttatus*
Wood Thrush	*Hylocichla mustelina*
Mockingbird	*Mimus polyglottos*
Brown Thrasher	*Toxostoma rufum*
European Starling	*Sturnus vulgaris*
Orange-crowned warbler	*Vermivora celata*
Northern Parula	*Parula americana*
Yellow-rumped Warbler	*Dendroica coronata*
Prothonotary Warbler	*Protonotaria citrea*
Kentucky Warbler	*Oporornis formosus*
Hooded Warbler	*Wilsonia citrina*
Summer Tanager	*Piranga rubra*
Northern Cardinal	*Cardinalis cardinalis*
Indigo Bunting	*Passerina cyanea*

Painted Bunting	*Passerina ciris*
Dickcissel	*Spiza americana*
White-throated sparrow	*Zonotrichia leucophrys*
Brown-headed Cowbird	*Molothrus ater*
Common Grackle	*Quiscalus quiacula*

Sources: Barry 2000; Dick and others 2003; Pulich 1988; Rylander 1959

APPENDIX C

LIST OF SPECIES RECOMMENDED FOR WET PRAIRIE, SEDGE MEADOW, AND

WET-MESIC PRAIRIE PLANTING FOR DENTON COUNTY

Table 36: List of species recommended for Wet Prairie, Sedge Meadow, and Wet-Mesic Prairie Planting for Denton County

SPECIES	COMMON NAME	HABITAT	CONSERV RANK	PROPAG	DURATION	WILDLIFE VALUE	OCCUR LLELA
Allium canadense	meadow garlic	WP,WM	1	S	P	2	Y
Amorpha fruticosa	bastard indigo	SM	5	S, R	P	6	Y
Andropogon gerardii	big bluestem	WP,WM	8	S	P-W	1,4,6,9	Y
Asclepias incarnata	swamp milkweed	SM	4-6	S	P	3,4,6,8	N
Aster lanceolatus	panicled aster	WP,WM	4	S	A	-	Y
Bidens frondosa	beggar's ticks	SM	1-3	S	A	-	Y
Carex blanda	charming caric sedge	WM	-	S,R,SP	P	-	Y
Carex crus-corvi	crow foot caric-sedge	WP	5	S,SP	P	10	Y
Carex festucacea	fecue-like caric sedge	WP	6-9	-	P	-	Y
Carex granularis	granular caric sedge	SM	2-4	R,S	P	-	N
Carex vulpinoidea	fox tail caric sedge	WP	1-4	S	P	1,10	N
Cicuta maculata	common water-hemlock	WP	3-6	-	B,P	-	N
Dodecatheon meadia	common shooting-star	WM	5-10	S	P	5,10,11	N
Eleocharis palustris	large spike spike-rush	WP	8	RH,S	P-W	1,7,9	Y
Elymus canadensis	Canada wild-rye	WM	5	S	P-C	1,6,7,9	Y
Equisetum hyemale	tall scouring-rush	SM	3	R	P	-	Y
Eupatorium perfoliatum	boneset	WP,SM	2-5	S,R	P	1,4	N
Helenium autumnale	common sneezeweed	WP,SM	3-7	S	P	4	N
Hypoxis hirsuta	yellow star-grass	WP	4-10	S,C	P	4,5	N
Juncus torreyi	Torrey's rush	SM	4	S,RH	P	-	Y
Liatris pycnostachya	Kansas gayfeather	WP,WM	6	S,R,C	P	4,5,11	N
Leersia oryzoides	rice cut grass	SM	1-4	RH	P-C	1,4,6,7,9	N
Lobelia siphilitica	big blue lobelia	SM	4-6	S,R	P	1,3	N
Lycopus americanus	water-horehound	SM	4	S	P	-	Y

Lythrum alatum	lance-leaf loosestrife	WP,WM	3	S	P	3	Y
Monarda fistulosa	wild bergamot	WM	2-6	S	P	1,3,4,11	N
Onoclea sensibilis	sensitive fern	SM	2-6	R	P	1	N
Oxypolis rigidor	cowbane	WP	6-9	-	P	-	N
Panicum virgatum	switchgrass	WP	6	S	P-W	1,4,6,9,10	Y
Phlox pilosa	prairie phlox	WP,WM	6-9	ST,R	P	1,4	N
Physostegia virginiana	obedient-plant	WP,WM	5-8	S,R	P	1,4	N
Rudbeckia hirta	black-eyed-Susan	WP,WM	1	S	S	1,3,4,5,6	Y
Rudbeckia triloba	brown-eyed-Susan	WM	3-6	-	P	1	N
Scirpus atrovirens	pale bulrush	SM	2-4	-	P	1,10	N
Scirpus cyperinus	wooly-grass bulrush	SM	1-7	S	P	1	N
Spartina pectinata	prairie cordgrass	SM,WP,WM	4-7	RH,S	P-W	1,9	N
Teucrium canadense	American germander	SM	2	S,RH	P	4	Y
Thalictrum dasycarpum	purple meadow-rue	WP,WM	3-8	S	P	-	N
Tripsacum dactyloides	eastern gamma grass	WP,WM	5	S	P-W	1,6,9,10,11	Y
Veronicastrum virginicum	Culver's root	WP,WM	6-10	R,S	P	4,5	N
Zizia aurea	golden-Alexanders	WP,WM	5-7	S	P	4,6	N

Sources: Buckallew 2007; Dick and others 2003; Galatowitsch and van der Walk 1998; Morgan 1997

PROPAG: Propagation method

S—seed
RH—rhizome transplant
R—root cutting
C—corm
ST—stem cutting
SP—sprig

WILDLIFE VALUE

1. food, birds
2. food, wild turkey
3. food, hummingbirds
4. attracts butterflies
5. attracts bees
6. larval host, butterfly
7. small mammal
8. muskrat
9. cover
10. graze
11. browse

HABITAT

SM—sedge meadow
WP—wet prairie
WM—wet-mesic prairie

APPENDIX D

OVAN CLAY SOIL MAPS

Figure 22. Ovan clay soils at LLELA

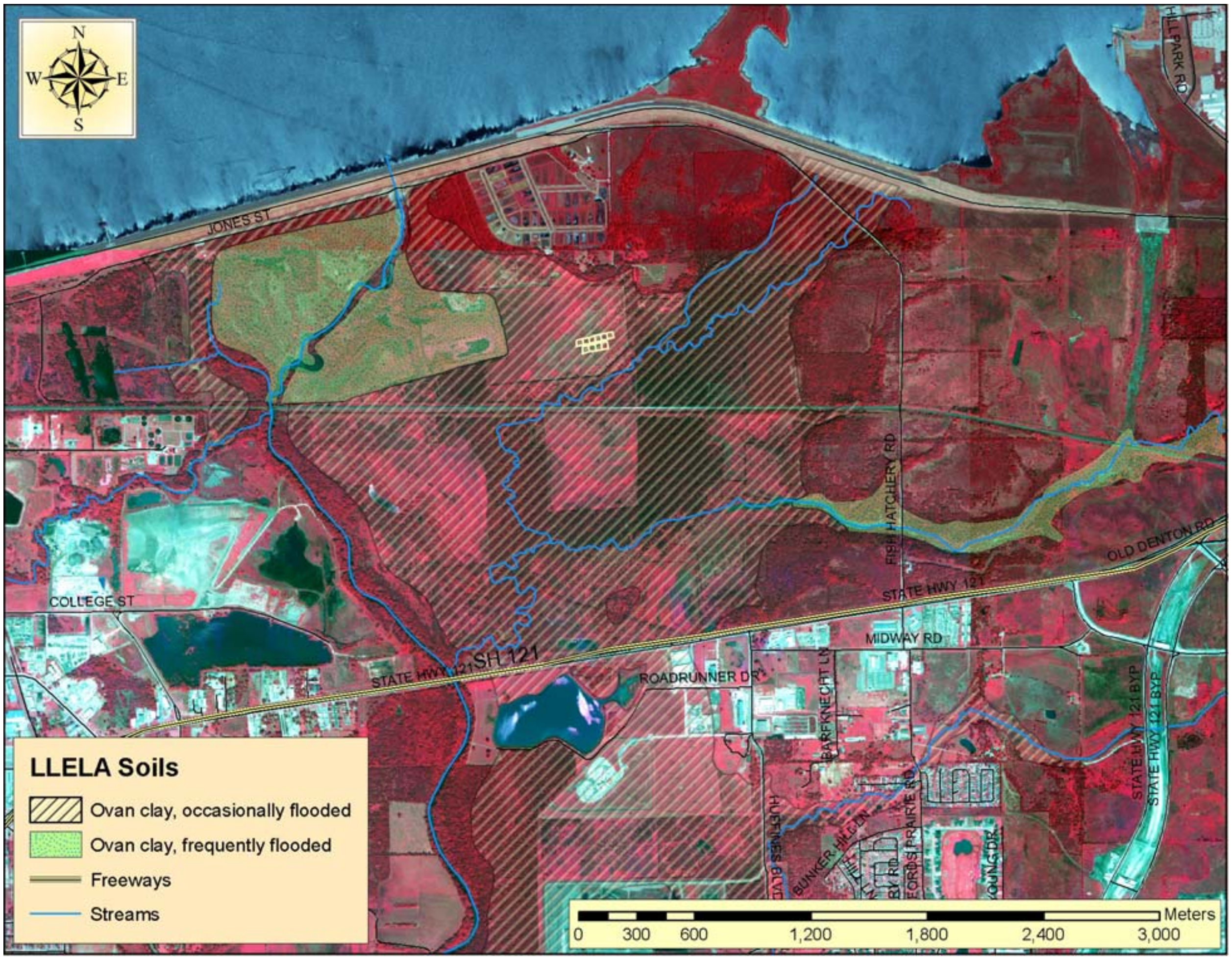
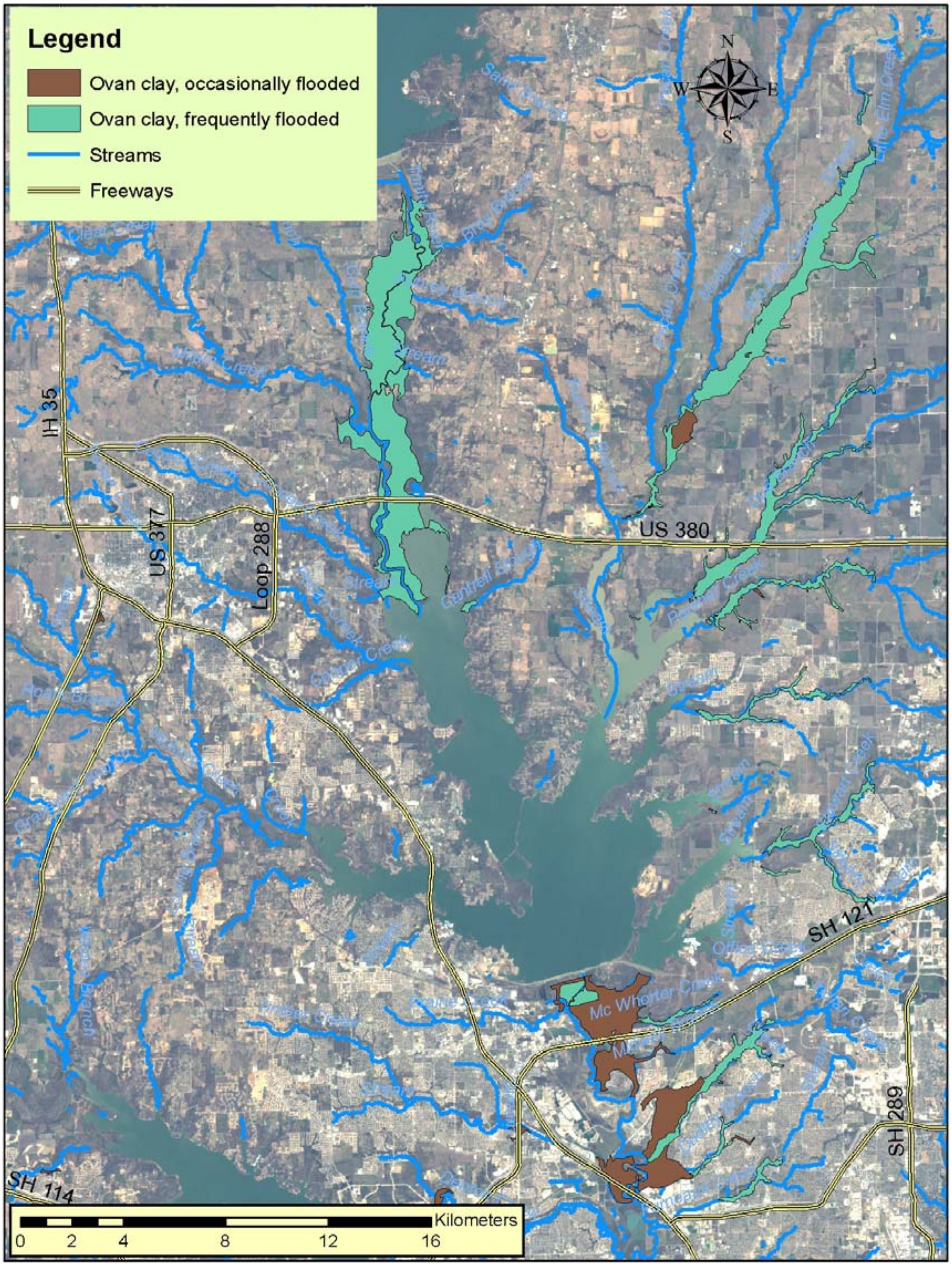


Figure 23. Ovan clay soils of eastern Denton County, Texas



APPENDIX E

RAW DATA VALUES FOR SURVIVAL AND GROWTH OF TREES

Oak-TerraSorb®

ID#	SRV fall '04	SRV sum '05	SRV fall '05	DIAM (mm) '05	HGHT (cm) '05	DIAM (mm) '06	HGHT (cm) '06	GROWTH DIAM (mm)	GROWTH HGHT (cm)
1	A	A	A	7.9	63.4	8.55	64.6	0.65	1.2
2	A	A	A	--	27.1	8.45	33	--	5.9
3	D	D	D	--	4.9	--	--	--	--
4	A	A	A	6.85	43	7.1	47	0.25	4
5	A	A	A	4.45	29.3	4.7	36.9	0.25	7.6
6	A	D	D	7.65	56.8	--	--	--	--
7	A	A	A	3.45	8	3.75	8.3	0.3	0.3
8	A	A	A	7.35	55	9.55	56	2.2	1
9	A	D	A	11.15	43	11.2	45.7	0.05	2.7
10	A	A	A	3.65	32.1	4.15	32.8	0.5	0.7
11	A	A	D	5.3	31.4	--	--	--	--
12	A	A	A	5.85	46	6.3	46.9	0.45	0.9
13	A	A	A	4.55	26.5	4.65	26.7	0.1	0.2
14	A	A	A	6.3	40.2	6.7	40.8	0.4	0.6
15	A	A	A	5.2	42.4	5.4	45	0.2	2.6
16	A	A	A	11.9	40.4	12.4	44.6	0.5	4.2
18	A	A	A	8.7	49.2	8.85	56.5	0.15	7.3
19	A	D	D	6.35	42.8	--	--	--	--
21	A	D	D	5.45	32	--	--	--	--
24	A	D	D	8.15	60.1	--	--	--	--
25	A	A	A	7.2	45	7.55	46.2	0.35	1.2
26	A	SNF	A	6.65	52.8	7.7	59.6	1.05	6.8
28	A	A	A	4.8	32	4.85	33.6	0.05	1.6
29	A	SNF	A	8.15	48.2	8.85	53.2	0.7	5
30	A	A	A	3.7	34.4	4	36.5	0.3	2.1
31	A	A	A	8.3	44	8.9	44.2	0.6	0.2
32	A	A	A	3.7	28.2	--	--	--	--
33	A	D	D	6.1	58.4	--	--	--	--
34	A	SNF	SNF	5.65	34	6.1	36	0.45	2
36	A	A	A	6.55	37	6.6	37.2	0.05	0.2
37	A	A	A	--	14	6.6	15.6		1.6
38	A	D	D	7.15	32.4	--	--	--	--
39	A	A	A	--	--	--	--	--	--
40	A	A	A	8.85	--	9	--	0.15	--
46	A	A	A	5	48.5	7	49.6	2	1.1
47	A	A	A	7	58	7.2	58.4	0.2	0.4
48	A	D	D	10.4	59	--	--	--	--
49	A	SNF	D	4.1	25.8	--	--	--	--
50	A	A	A	--	45	6.35	45.6	--	0.6
51	A	A	A	--	31.2	11.7	33.4	--	2.2
52	A	A	A	10.65	69	11.7	72	1.05	3
54	A	A	A	8.8	53.7	9.1	54.6	0.3	0.9
55	A	A	A	4.25	12.6	4.65	14	0.4	1.4
57	A	D	D	8.2	37.6	--	--	--	--
58	A	A	A	--	44.2	7.25	44.8	--	0.6
59	A	SNF	SNF	8.75	45.2	--	--	--	--
62	A	A	A	10.75	48.2	11.15	54.6	0.4	6.4
69	A	A	A	7.7	44.5	7.8	49.6	0.1	5.1
70	A	A	D	4.7	42.8	--	--	--	--
76	A	D	D	6.9	23	--	--	--	--
80	A	D	D	6.85	58.8	--	--	--	--
81	A	D	D	5.85	30.2	--	--	--	--
84	A	A	A	5.5	22.2	5.7	25	0.2	2.8
A	A	A	A	--	36.2	6.4	39	--	2.8
B	A	SNF	A	4.75	32.2	5.25	36.9	0.5	4.7
C	A	NF	NF	6.8	49.4	--	--	--	--
D	A	A	A	10.25	82.2	--	--	--	--
E	A	NF	NF	4.1	14	--	--	--	--
F	A	A	A	7.8	37	8.2	41.2	0.4	4.2

G	A	SNF	D	9.4	73	--	--	--	--

SURV--Survival
DIAM—Diamteter
HGHT—Height
A—alive
D—dead
NF—tree not found
SNF—site not found (no tree, tag, or flag)

Oak-Control

ID#	SRV fall '04	SRV sum '05	SRV fall '05	DIAM (mm) '05	HGHT (cm) '05	DIAM (mm) '06	HGHT (cm) '06	GROWTH DIAM (mm)	GROWTH HGHT (cm)
1	A	D	D	7	35	--	--	--	--
2	A	A	A	--	-	9.65	72.2	--	--
3	A	D	D	5.15	51	--	--	--	--
4	A	A	D	5.6	46	--	--	--	--
7	A	A	A	5.85	45	7.2	51	1.35	6
10	A	SNF	SNF	4.35	33	--	--	--	--
11	A	SNF	SNF	6	46	--	--	--	--
13	A	A	A	6.6	67	7.7	68	1.1	1
17	A	D	D	5.9	51	--	--	--	--
18	A	A	A	4.2	--	5.35	45.2	1.15	--
19	A	A	A	5.7	32	5.75	39.6	0.05	7.6
22	A	D	D	9.15	54	--	--	--	--
24	A	D	D	5.95	46	--	--	--	--
25	A	A	A	10	60	10.85	60.4	0.85	0.4
26	D	D	D	5.3	48	--	--	--	--
27	A	A	A	5.5	43	6.45	43.8	0.95	0.8
31	A	D	D	7.45	62	--	--	--	--
34	A	SNF	SNF	6.35	45	--	--	--	--
37	A	D	D	8.4	71	--	--	--	--
41	A	A	A	5.3	55	7	55.1	1.7	0.1
45	A	A	A	2.85	--	4.55	20.2	1.7	--
50	A	NF	NF	5.55	21	--	--	--	--
52	A	NF	NF	6.15	34	--	--	--	--
53	A	A	A	5.5	50	5.7	50.2	0.2	0.2
55	A	A	A	8.75	36	8.75	36.2	0	0.2
58	D	D	D	4.65	26	--	--	--	--
61	A	D	D	7	63	--	--	--	--
63	A	A	A	5.55	24	5.55	26	0	2
65	A	D	D	4.05	42	--	--	--	--
67	A	A	A	8.1	64	8.35	66	0.25	2
69	A	D	D	4.45	50	--	--	--	--
71	A	A	D	6.1	52	--	--	--	--
73	A	SNF	NF	6.1	63	--	--	--	--
74	A	D	D	3.85	42	--	--	--	--
76	A	NF	SNF	6.55	60	--	--	--	--
81	D	D	D	4.2	41	--	--	--	--
83	A	A	D	6.05	41	--	--	--	--
87	A	D	D	4.85	54	--	--	--	--
90	A	A	D	7.8	54	--	--	--	--
91	D	D	A	4.2	18	4.85	23	0.65	5
94	A	D	D	10	63	--	--	--	--
97	A	A	A	7.2	51	7.8	51.2	0.6	0.2
98	A	A	A	6.3	58	8.05	58.9	1.75	0.9
99	A	NF	D	6.2	42	--	--	--	--

SURV--Survival
DIAM—Diamteter
HGHT—Height
A—alive
D—dead
NF—tree not found
SNF—site not found (no tree, tag, or flag)

Oak-Mycorrhiza

ID#	SRV fall '04	SRV sum '05	SRV fall '05	DIAM (mm) '05	HGHT (cm) '05	DIAM (mm) '06	HGHT (cm) '06	GROWTH DIAM (mm)	GROWTH HGHT (cm)
2	A	A	A	--	23.8	4.05	27.2	--	3.4
3	D	D	D	7.2	30	--	--	--	--
7	A	D	D	8.1	34	--	--	--	--
8	A	D	D	5.1	29.6	--	--	--	--
10	A	A	A	13.3	51	13.35	54	0.05	3
16	D	D	D	9.85	54.4	--	--	--	--
20	D	D	D	12	28	--	--	--	--
28	A	A	A	6.6	--	7	--	0.4	--
32	A	A	A	--	40.4	5.55	44.6	--	4.2
37	A	D	D	10.95	80	--	--	--	--
39	A	A	A	7.25	45.4	7.65	49.4	0.4	4
43	A	A	A	8.3	57	8.7	60.4	0.4	3.4
48	A	D	D	3.35	24.6	--	--	--	--
49	D	D	D	15.85	43.5	--	--	--	--
53	A	D	D	10.45	57	--	--	--	--
55	A	D	D	4.4	31.8	--	--	--	--
71	A	SNF	A	--	76.6	7.1	78.2	--	--
75	A	D	D	8.7	5.6	--	--	--	--
78	A	SNF	D	10.65	70	--	--	--	--
79	A	D	D	6.1	53	--	--	--	--
80	A	SNF	SNF	10.8	45.6	--	--	--	--
81	A	A	D	5.75	44	--	--	--	--
082x	A	A	D	6.05	44.8	--	--	--	--
83	A	D	D	8.2	48	--	--	--	--
84	A	SNF	SNF	10.45	53	--	--	--	--
86	A	D	D	8	46	--	--	--	--
91	A	D	A	12.2	49.8	--	--	--	--
92	A	A	A	--	--	2.3	25	--	--
94	A	NF	NF	6.35	46	--	--	--	--
99	A	SNF	A	8.6	48	8.9	51	0.3	3
102	A	NF	NF	4.9	33.8	--	--	--	--

SURV--Survival
DIAM—Diamteter
HGHT—Height
A—alive
D—dead
NF—tree not found
SNF—site not found (no tree, tag, or flag)

Oak-DRiWATER®

ID#	SRV fall '04	SRV sum '05	SRV fall '05	DIAM (mm) '05	HGHT (cm) '05	DIAM (mm) '06	HGHT (cm) '06	GROWTH DIAM (mm)	GROWTH HGHT (cm)
10	A	A	A	8.4	60.5	9.4	64	1	3.5
11	A	A	A	6.25	36.8	6.25	37.4	0	0.6
12	A	D	D	5.95	34	--	--	--	--
16	A	A	D	7.55	61	--	--	--	--
18	A	D	D	5.5	27	--	--	--	--
23	A	A	A	8.1	72.6	9.7	77.8	1.6	5.2
26	A	D	D	6	33.8	--	--	--	--
31	A	D	D	6.65	51.8	--	--	--	--
32	A	D	D	6.7	46.4	--	--	--	--
34	A	D	D	5.5	38.4	--	--	--	--
35	A	A	D	3.2	23	--	--	--	--
37	A	A	A	5	28.2	5.5	28.4	0.5	0.2
42	A	D	D	7.2	51	--	--	--	--
45	D	D	D	12.6	73	--	--	--	--
46	A	A	A	--	41.6	6.1	41.8	--	0.2
47	A	A	A	4.5	38	5.1	45.8	0.6	7.8
49	A	A	A	7.2	58.6	7.9	60.4	0.7	1.8
51	D	D	D	5.15	29.4	--	--	--	--
56	A	D	D	9.6	47.2	--	--	--	--
57	A	A	A	7.05	28	7.05	29	0	1
60	A	A	D	6.6	31.5	--	--	--	--
61	A	A	A	6.3	40.2	7	49.2	0.7	9
62	A	D	D	6.1	55.6	--	--	--	--
66	A	D	D	8	97.2	--	--	--	--
69	A	A	A	5.4	41.4	5.5	43	0.1	1.6
74	A	SNF	D	4.95	24.6	--	--	--	--
75	A	A	A	4.15	27	4.65	27.5	0.5	0.5
78	A	SNF	A	5.55	43	5.9	44	0.35	1
80	A	A	A	11.95	--	12	41.4	0.05	--
81	A	A	A	5.85	21.8	6	23.8	0.15	2
85	A	D	D	4.4	46	--	--	--	--
86	A	D	D	6.9	44.6	--	--	--	--
90	A	A	A	5.7	33	6.5	34.1	0.8	1.1
94	A	D	D	8.4	68	--	--	--	--

SURV--Survival
DIAM—Diamteter
HGHT—Height
A—alive
D—dead
NF—tree not found
SNF—site not found (no tree, tag, or flag)

Oak-Mulch

ID#	SRV fall '04	SRV sum '05	SRV fall '05	DIAM (mm) '05	HGHT (cm) '05	DIAM (mm) '06	HGHT (cm) '06	GROWTH DIAM (mm)	GROWTH HGHT (cm)
10	A	D	D	5	44.6	--	--	--	--
16	A	D	D	9.4	43.6	--	--	--	--
19	A	D	D	11.7	57	--	--	--	--
24	A	D	D	5.8	51.6	--	--	--	--
29	A	D	D	11.2	39.8	--	--	--	--
30	A	D	D	9.85	49.4	--	--	--	--
31	A	D	D	12.35	50	--	--	--	--
33	A	D	D	10	55.7	--	--	--	--
34	A	A	A	6.05	29.2	6.5	31	0.45	1.8
35	A	D	D	2.95	28.8	--	--	--	--
36	A	D	D	13.3	77.8	--	--	--	--
37	A	D	D	10.1	56.4	--	--	--	--
42	A	D	D	11.6	50.2	--	--	--	--
43	A	A	D	6.4	47	--	--	--	--
44	A	D	D	9.05	54	--	--	--	--
46	A	A	A	6.5	42.8	6.85	45	0.35	2.2
47	A	A	D	9.8	59.2	--	--	--	--
49	A	D	D	6.15	47.2	--	--	--	--
50	A	SNF	D	6.7	37.6	--	--	--	--
51	A	A	A	4.35	29.2	4.6	31.2	0.25	2
52	A	D	D	4.8	25	--	--	--	--
53	A	A	A	6.1	35	6.55	36.4	0.45	1.4
56	A	A	A	6.35	40	6.45	45.1	0.1	5.1
57	A	D	D	5.6	41.4	--	--	--	--
58	A	A	D	6.65	58.2	--	--	--	--
60	A	A	D	9.4	67.4	--	--	--	--
64	A	A	D	8	36.2	--	--	--	--
65	A	D	D	5.1	36.6	--	--	--	--
67	A	D	D	5.75	29.4	--	--	--	--
69	A	D	D	6.9	59	--	--	--	--
72	A	D	D	5	40	--	--	--	--
73	A	D	D	9.1	36	--	--	--	--
77	A	D	D	5.9	48.8	--	--	--	--
78	A	D	D	7.7	68.8	--	--	--	--
80	A	D	D	13.5	49.4	--	--	--	--
81	A	A	A	10.35	73	12.9	77	2.55	4
83	A	D	D	5.25	35.2	--	--	--	--
84	A	A	A	14.05	--	14.65	69.1	0.6	--
89	A	D	D	10.1	54.8	--	--	--	--
90	A	D	D	6.05	53	--	--	--	--
91	A	D	D	11	57.6	--	--	--	--
92	A	D	D	13.1	39.6	--	--	--	--
93	A	D	D	6.1	35	--	--	--	--
94	A	A	A	--	54.8	7.2	55.2	--	0.4
44x	A	SNF	SNF	6.4	69	--	--	--	--
43x	A	SNF	SNF	6.95	50.8	--	--	--	--

SURV--Survival
DIAM—Diamteter
HGHT—Height
A—alive
D—dead
NF—tree not found
SNF—site not found (no tree, tag, or flag)

Ash-DRiWATER®

ID#	SRV fall '04	SRV sum '05	SRV fall '05	DIAM (mm) '05	HGHT (cm) '05	DIAM (mm) '06	HGHT (cm) '06	GROWTH DIAM (mm)	GROWTH HGHT (cm)
1	A	A	A	9.65	69.2	20.85	76.9	11.2	7.7
2	A	A	A	18.15	79.6	23.55	109.1	5.4	29.5
3	A	A	A	11.9	50.1	15	66.2	3.1	16.1
4	A	A	A	10.05	49.6	18.15	75.8	8.1	26.2
5	A	A	A	11.5	44.2	14.45	78.2	2.95	34
6	A	A	A	10.85	48.4	12.3	54.5	1.45	6.1
7	A	A	A	13.6	60.4	14.7	80.3	1.1	19.9
8	A	A	A	10.4	44	13	62.2	2.6	18.2
9	A	A	A	8.25	30	9.65	46.1	1.4	16.1
10	A	A	A	15.9	54.2	19.05	80.8	3.15	26.6
12	A	A	A	13.8	48.8	15.15	64.6	1.35	15.8
13	A	A	A	13.7	56.6	16	62.4	2.3	5.8
14	A	A	A	10.15	48.2	11.35	81.4	1.2	33.2
15	A	A	A	12.25	80.8	21.7	124.5	9.45	43.7
16	A	A	A	11.9	51.4	13.35	57.6	1.45	6.2
17	A	A	A	12.6	68.8	14.2	85	1.6	16.2
18	A	A	A	14.85	66	22.3	92.3	7.45	26.3
19	A	A	A	18.85	94.8	22	117.4	3.15	22.6
20	A	A	A	10.15	51.2	11.55	66.8	1.4	15.6
21	A	A	A	21.5	114.8	24.7	129.8	3.2	15
22	A	A	A	14.4	46.2	15.5	64.6	1.1	18.4
23	A	A	A	9.7	50.2	11.35	63.6	1.65	13.4
26	A	A	A	9.25	32.2	11.2	51.6	1.95	19.4
27	A	A	A	9.9	62.2	17.85	84.1	7.95	21.9
28	NF	SNF	A	19	74.6	21.85	102.4	2.85	27.8
29	A	A	A	12.95	66.4	14.3	88.5	1.35	22.1
31	A	A	A	15.65	56.6	19.65	77.8	4	21.2
32	A	A	A	11.1	52.5	13.8	80.5	2.7	28
33	A	A	A	13.2	60.5	15.15	80.7	1.95	20.2
34	A	A	A	13.9	41.6	18.35	85.5	4.45	43.9
35	A	A	A	13.7	57.2	18.4	87.4	4.7	30.2
36	A	A	A	6.75	37.2	8.2	44	1.45	6.8
37	A	A	A	12.7	50.4	16	77.8	3.3	27.4
38	A	A	A	10.05	34.6	11.15	44.2	1.1	9.6
39	A	A	A	11.05	65	13.05	82.6	2	17.6
41	A	A	A	15.5	64.8	16.7	76.1	1.2	11.3
42	A	A	A	18.7	76.2	22.85	111.9	4.15	35.7
43	A	A	A	13.95	62	18.4	83	4.45	21
44	A	A	A	18.05	63.2	22.8	84.3	4.75	21.1
45	A	A	A	15.35	70.2	17.4	92	2.05	21.8
46	A	A	A	18.4	94.4	22.2	121.2	3.8	26.8
47	A	A	A	11.55	68.8	17.35	96.6	5.8	27.8
48	A	A	A	11.6	54.2	17.85	89.2	6.25	35
49	A	A	A	15.5	71.2	18.95	102.4	3.45	31.2
50	A	A	A	10.45	62.2	13.8	85.5	3.35	23.3
53	A	A	A	13.55	44.8	19.5	80.2	5.95	35.4
54	A	A	D	11.5	--	12.25	45.4	0.75	--
55	A	A	A	22	79.8	26.35	104.2	4.35	24.4
56	A	A	A	20.85	62.2	24.1	79.7	3.25	17.5
57	A	A	A	12.3	45	13.9	48.8	1.6	3.8
58	A	A	A	12.9	54.2	17.65	64.4	4.75	10.2
59	A	A	A	13.95	66	17.4	86.6	3.45	20.6
60	A	A	A	26.1	128.6	30.8	150.5	4.7	21.9
61	A	A	A	18.8	104.6	21.1	106	2.3	1.4
62	A	A	A	15.4	74.4	16.6	87.7	1.2	13.3
63	A	A	A	--	73.3	11.85	85.2	--	11.9
64	A	A	A	22.4	96.4	24.15	113.9	1.75	17.5
65	A	A	A	18.15	81.4	22.65	121.2	4.5	39.8
66	A	A	A	19.8	104.2	24	153.6	4.2	49.4

67	A	A	A	18.9	80	21.85	105.7	2.95	25.7
68	A	A	A	12.4	77.3	16.15	107.2	3.75	29.9
69	A	A	A	19.45	80	22.8	109.5	3.35	29.5
70	A	A	A	14.7	57.8	17.35	85.9	2.65	28.1
71	A	A	A	17.1	54.4	17.45	73	0.35	18.6
72	A	A	A	17.2	71	21.55	94	4.35	23
73	A	A	A	17.6	80.8	21.45	111.4	3.85	30.6
74	A	A	A	11.5	56	14.9	72.6	3.4	16.6
75	A	A	A	15.05	54	19.6	87.8	4.55	33.8
76	A	A	A	12.6	63	14.9	82.6	2.3	19.6
77	A	A	A	9.45	51	13.7	82	4.25	31
78	A	A	A	13.5	74.2	19.4	98.4	5.9	24.2
81	A	A	A	14.75	61.8	17.7	75.4	2.95	13.6
82	A	A	A	12.05	66	15.2	83.4	3.15	17.4
84	A	A	A	11.45	56.4	14.8	73.7	3.35	17.3
86	A	A	A	9.2	42.8	10.55	52.6	1.35	9.8
87	A	A	A	7.85	43.6	9.7	56	1.85	12.4
88	A	A	A	11.1	63.6	15.65	94.1	4.55	30.5
89	A	A	A	9.9	89.6	17.65	98	7.75	8.4
90	A	A	A	13.7	59.2	17.5	84.4	3.8	25.2
91	A	A	A	13	65.4	15.2	84.5	2.2	19.1
92	A	A	A	24.85	81.6	30.85	110.3	6	28.7
93	A	A	A	13.4	59.4	15.85	89.2	2.45	29.8
094	A	A	A	13.7	89	16.65	115.4	2.95	26.4

SURV--Survival
DIAM—Diamteter
HGHT—Height
A—alive
D—dead
NF—tree not found
SNF—site not found (no tree, tag, or flag)

Ash-Mulch

ID#	SRV fall '04	SRV sum '05	SRV fall '05	DIAM (mm) '05	HGHT (cm) '05	DIAM (mm) '06	HGHT (cm) '06	GROWTH DIAM (mm)	GROWTH HGHT (cm)
1	A	A	A		104.8	28.25	118.7	--	13.9
2	A	A	A	10.7	72.6	13.15	105.1	2.45	32.5
3	A	A	A	12	66	15.1	78.5	3.1	12.5
4	A	A	A	9.9	62.2	13.55	70	3.65	7.8
6	A	A	A	13.55	70.8	20	100.8	6.45	30
7	A	A	A	23.9	89	27.05	111.9	3.15	22.9
8	A	A	A	13.7	58.4	17.25	89	3.55	30.6
9	A	A	A	10.65	35.2	13.1	59.3	2.45	24.1
10	A	A	A	18.25	59.3	23.45	86.2	5.2	26.9
11	A	A	A	10.35	81.5	19.25	111	8.9	29.5
12	A	A	A	18.3	78	26.75	97.8	8.45	19.8
13	A	A	A	15.7	77.4	17.85	99	2.15	21.6
14	A	A	A	21.6	83.2	23.6	94	2	10.8
16	A	A	A	15.95	49.6	17.65	63.4	1.7	13.8
17	A	A	?	9.9	38	12.75	50.6	2.85	12.6
19	A	A	A	17.35	73.2	19.15	85	1.8	11.8
21	A	A	A	19.3	102.4	22	122.2	2.7	19.8
22	A	A	A	22.3	72.8	26.45	93.2	4.15	20.4
24	A	A	?	16.5	68	19.9	93.4	3.4	25.4
25	A	A	A	27.4	113.2	28.8	132.7	1.4	19.5
26	A	A	A	14.65	80.8	15.6	91.9	0.95	11.1
27	A	A	A	20.05	98	27.15	113.3	7.1	15.3
28	A	A	A	19	65.6	22.8	76.3	3.8	10.7
29	A	A	A	16.55	89	20.95	114	4.4	25
30	A	A	A	12.75	50.2	15.55	62.6	2.8	12.4
31	A	A	A	19.75	92.7	24.15	119.2	4.4	26.5
32	A	A	A	22.15	98.8	24.3	113.4	2.15	14.6
33	A	A	A	9.55	86.6	18.95	106.8	9.4	20.2
34	A	A	A	18.8	94.4	20.9	105.4	2.1	11
35	A	A	A	11.5	81.2	20	113.7	8.5	32.5
36	A	A	A	13.95	73.4	17.7	99.6	3.75	26.2
37	A	A	?	25.65	40	27.4	101.1	1.75	61.1
38	A	A	A	20.1	75.6	22.45	87.4	2.35	11.8
39	A	A	A	29.8	134	33.95	154.8	4.15	20.8
40	A	A	A	24	84.6	26.35	106.3	2.35	21.7
41	A	A	A	14.05	73.8	15.9	95	1.85	21.2
42	A	A	A	13.3	63.6	16	85.1	2.7	21.5
43	A	A	A	20.1	83.2	23.65	117.4	3.55	34.2
44	A	A	A	19.05	72.1	23.85	127.4	4.8	55.3
45	A	A	A	12	70.8	17.25	109.4	5.25	38.6
46	A	A	A	20.65	57.8	25.05	81.6	4.4	23.8
47	A	A	A	19	116.7	21.55	129.2	2.55	12.5
48	A	A	A	11.8	59	12.85	75.6	1.05	16.6
49	A	A	A	27.05	107.6	31.35	114.8	4.3	7.2
50	A	A	A	15.95	51.2	21	71.5	5.05	20.3
51	A	A	A	10.2	47.2	14.8	64.6	4.6	17.4
52	A	A	A	15	67	15.2	70.4	0.2	3.4
53	A	A	A	20.1	74.8	24.15	101.2	4.05	26.4
54	A	A	A	10.1	38.2	10.65	52.9	0.55	14.7
55	A	A	A	19.9	58	21.35	74.3	1.45	16.3
56	A	A	A	20.15	105.2	29.05	146	8.9	40.8
57	A	A	A	27.2	108.2	30.1	124	2.9	15.8
58	A	A	A	24.8	102	35	127.4	10.2	25.4
59	A	A	A	26.9	93.1	31.85	134.2	4.95	41.1
61	A	A	A	28.45	85.4	34.45	121	6	35.6
62	A	A	A	21.55	73.8	25.4	95	3.85	21.2
63	A	A	A	11.3	66.6	17.6	82.2	6.3	15.6
64	A	A	A	17.4	72.6	19.7	94.8	2.3	22.2
65	A	A	A	18.8	82	24.5	109.6	5.7	27.6

67	A	A	A	30.1	129.8	37.3	158.2	7.2	28.4
70	A	A	A	19.55	56.4	20.7	77.4	1.15	21
71	A	A	A	22.25	64.8	25.15	130.1	2.9	65.3
72	A	A	A	18.75	88.8	22.45	99.8	3.7	11
73	A	A	A	19.8	65	20.45	94.2	0.65	29.2
74	A	A	A	19.3	83	20.65	95.8	1.35	12.8
76	A	A	A	17.7	74.9	21.15	103.1	3.45	28.2
77	A	A	A	--	109	24.55	121.5	--	12.5
78	A	A	A	12.45	47	15	64.1	2.55	17.1
79	A	A	A	18.7	60.8	22.8	85.2	4.1	24.4
80	A	A	A	11.45	53	14.1	63.9	2.65	10.9
81	A	A	A	14.3	66.6	17.95	75.2	3.65	8.6
82	A	A	A	14.7	56.4	16.05	75.2	1.35	18.8
84	A	A	A	9	40.4	13	79.1	4	38.7
86	**A**	**A**	**A**	20	93.2	21.7	108.2	1.7	15
87	A	A	A	12	51.4	14.05	62	2.05	10.6
88	A	A	A	12.2	71.2	20.6	126.1	8.4	54.9
89	A	A	A	18.8	86	20.7	106.6	1.9	20.6
90	A	A	A	22.5	97	27.3	124.1	4.8	27.1
91	A	A	A	19.7	77.4	23.4	105.3	3.7	27.9
92	A	A	A	13.3	44.4	15.6	64.8	2.3	20.4
93	A	A	A	16.75	60	18.3	80	1.55	20
94	A	A	A	17.15	67	18.85	78.4	1.7	11.4
95	A	A	A		40.6	15.4	69.4	--	28.8
97	A	SNF	A	20.85	87.2	24.4	119.2	3.55	32
98	A	SNF	SNF	7.8	43	--	--	--	--
99	A	A	A	28.85	125.8	31.55	143.7	2.7	17.9
100	A	A	A	24.1	91.8	26.8	121.5	2.7	29.7
102	A	A	A	21.65	97.2	22.2	108	0.55	10.8
103	A	A	A	17.95	107	20.5	119.8	2.55	12.8
67x	A	NF	A	22.2	105	34.15	136.8	11.95	31.8
100x	A	NF	A	25.8	119.2	29.4	135.6	3.6	16.4

SURV--Survival
DIAM—Diamteter
HGHT—Height
A—alive
D—dead
NF—tree not found
SNF—site not found (no tree, tag, or flag)

Ash-Mycorrhiza

ID#	SRV fall '04	SRV sum '05	SRV fall '05	DIAM (mm) '05	HGHT (cm) '05	DIAM (mm) '06	HGHT (cm) '06	GROWTH DIAM (mm)	GROWTH HGHT (cm)
1	A	A	A	12.05	54	13.2	56.9	1.15	2.9
2	A	A	A	12.6	32.6	13.95	48.4	1.35	15.8
3	A	A	A	--	59.6	12.35	56.3	--	--
4	A	A	A	19.4	72	19.85	91.7	0.45	19.7
5	A	A	A	8.25	43.2	14.75	74.5	6.5	31.3
7	A	A	A	9.85	62.4	14.05	80.5	4.2	18.1
8	A	A	A	16.8	54.8	18.05	60.2	1.25	5.4
9	A	A	A	13.25	63	14.6	68.8	1.35	5.8
10	A	A	A	14.05	64.5	16.5	83.8	2.45	19.3
11	A	A	A	16.9	55.8	18	66.4	1.1	10.6
12	A	A	A	16	73.2	18	91.1	2	17.9
13	A	A	A	15.45	48.4	15.85	65	0.4	16.6
14	A	A	A	11.85	64	14.55	78.4	2.7	14.4
15	A	A	A	23.5	74	24.2	110.4	0.7	36.4
16	A	A	A	11.15	53	12	64.3	0.85	11.3
17	A	A	A	12.5	52.8	14.4	67.6	1.9	14.8
18	A	A	A	16.3	74.6	19.55	93.7	3.25	19.1
19	A	A	A	18.45	78.6	20.15	89.3	1.7	10.7
20	A	A	A	12.1	51.2	13.85	64.4	1.75	13.2
21	A	A	A	11.1	53.2	11.35	56.4	0.25	3.2
22	A	A	A	15.1	60.4	15.1	62.9	0	2.5
24	A	A	A	10.95	55.6	13.8	63.6	2.85	8
25	A	A	A	10.1	53	12	66	1.9	13
26	A	A	A	14.5	63.8	17.7	83.2	3.2	19.4
27	A	A	A	23.3	91.2	23.3	114.4	0	23.2
28	A	A	A	16.15	53.2	17	74.7	0.85	21.5
29	A	A	A	23.25	89.6	24.1	91.2	0.85	1.6
30	A	A	A	22.2	67	22.75	90.2	0.55	23.2
31	A	A	A	--	64.4	19.4	84.3	--	19.9
32	A	A	A	21.45	89.2	21.85	101.4	0.4	12.2
33	A	A	A	--	53.8	11.85	61.3	--	7.5
35	A	A	A	11.8	58	13.5	70.2	1.7	12.2
36	A	A	A	--	44	10.8	52.4	---	8.4
37	A	A	A	11.6	49	13.2	55.5	1.6	6.5
38	A	A	A	11.1	44.2	13.9	60.3	2.8	16.1
39	A	A	A	--	39.8	12.8	41.8	--	2
40	A	A	A	8.9	47.6	9.55	46.8	0.65	--
41	A	A	A	--	73.2	19	92.2	--	19
42	A	A	A	10.55	41	12.35	55.7	1.8	14.7
43	A	A	A	27.45	101.8	29.2	107.3	1.75	5.5
44	A	A	A	20.1	60.6	20.9	96.7	0.8	36.1
45	A	A	A	--	44	13.55	54.2	--	10.2
47	A	A	A	--	36.8	8.35	39.9	--	3.1
48	A	A	A	18.65	83.4	22.8	105.2	4.15	21.8
49	A	A	A	16.8	64.4	17.25	69.2	0.45	4.8
50	A	A	A	13.9	58.2	15.05	66.5	1.15	8.3
51	A	A	A	9.9	52.4	10.35	51.7	0.45	--
53	A	A	A	14.7	60	16.25	68.6	1.55	8.6
54	A	A	A	10.7	46.6	12.4	48.1	1.7	1.5
55	A	A	A	16.05	74	24.35	114.5	8.3	40.5
56	A	A	A	18.1	96.4	23.4	129	5.3	32.6
57	A	A	A	15.8	67.6	19.9	73.5	4.1	5.9
58	A	A	A	12.5	62.4	17.95	71.2	5.45	8.8
59	A	A	A	11.5	38	12.75	45.8	1.25	7.8
60	A	A	A	13.95	59.4	16.9	75.6	2.95	16.2
62	A	A	A	15.6	60.6	18	93.6	2.4	33
63	A	A	A	13.3	76	20.9	103.2	7.6	27.2
64	A	A	A	12.7	54.6	15.05	60.6	2.35	6
65	A	A	A	--	53	14.25	62.6	--	9.6

66	A	A	A	9.95	53	11.4	67	1.45	14
67	A	A	A	--	60.6	15.8	64	--	3.4
68	A	A	A	18.3	66.4	19.15	84.2	0.85	17.8
69	A	A	A	20.3	65.6	--	85.7	--	20.1
70	A	A	A	--	69.4	15	75.2	--	5.8
73	A	A	A	7	32	7.75	51	0.75	19
75	A	A	A	10.05	55	12.2	84.8	2.15	29.8
76	A	A	A	32.95	126.4	34	147.2	1.05	20.8
77	A	A	A	--	47.4	11	50.7	--	3.3
78	A	A	A	12.85	46.6	20.17	99.5	7.32	52.9
79	A	A	A	--	--	15.95	61	--	--
80	A	A	A	--	60.2	14.9	83.5	--	23.3
81	A	SNF	A	13.65	50.2	16.7	91.6	3.05	41.4
82	A	A	A	17.75	70.2	20.4	83.5	2.65	13.3
83	A	A	A	13.8	77.8	19.4	90.3	5.6	12.5
84	A	A	A	16.6	55.4	21.4	64.6	4.8	9.2
85	A	A	A	15	66	15.4	83.2	0.4	17.2
86	A	A	A	11.7	50.6	12.7	53.1	1	2.5
87	A	A	A		37.2	12.4	42.5	--	5.3
89	A	SNF	A	14.2	70	16.85	80.7	2.65	10.7
90	A	A	A	11.35	54.4	15.1	80.4	3.75	26
91	A	A	A	17.8	80.8	17.8	94.9	0	14.1
92	A	A	A	11.2	73	15.55	96.4	4.35	23.4
93	A	A	A	11.65	57.2	15.05	67.5	3.4	10.3
94	A	SNF	A	17.35	49	17.45	49.5	0.1	0.5
95	A	A	A	18.5	60.4	18.75	82.3	0.25	21.9
008x	A	SNF	SNF	23.45	74.4	--	--	--	--

SURV--Survival
DIAM—Diamteter
HGHT—Height
A—alive
D—dead
NF—tree not found
SNF—site not found (no tree, tag, or flag)

Ash-Control

ID#	SRV fall '04	SRV sum '05	SRV fall '05	DIAM (mm) '05	HGHT (cm) '05	DIAM (mm) '06	HGHT (cm) '06	GROWTH DIAM (mm)	GROWTH HGHT (cm)
1	A	A	A	9.2	76.9	15.95	97.4	6.75	20.5
2	A	A	A	11.5	72	16.65	84.2	5.15	12.2
3	A	A	A	12	68.1	16.65	77.4	4.65	9.3
4	A	A	A	12.9	77.8	17.25	86	4.35	8.2
5	A	A	A	20.6	77	22.05	102.4	1.45	25.4
6	A	A	A	13.3	76.4	19.15	88.1	5.85	11.7
7	A	A	A	12.75	60.6	12.9	63.4	0.15	2.8
8	A	A	A	10.7	51.6	13.8	56.6	3.1	5
9	A	A	A	12.6	59	15.3	99.9	2.7	40.9
10	A	A	A	13.65	73.7	15.4	76.8	1.75	3.1
12	A	A	A	13.85	63	15.35	68.5	1.5	5.5
13	A	A	A	13.2	56.6	13.6	60.2	0.4	3.6
14	A	A	A	9.85	50.2	10.95	58	1.1	7.8
15	A	A	A	11.05	53.8	11.45	56	0.4	2.2
16	A	A	A	8.9	56.6	14.2	72.6	5.3	16
17	A	A	A	11.45	52.8	16.95	84.3	5.5	31.5
18	A	A	A	19.7	87	22.55	108.7	2.85	21.7
19	A	A	A	11.85	47.4	12.4	54	0.55	6.6
20	A	A	A	--	73	15.1	95.2	--	22.2
21	A	A	A	13.9	60	14.9	78.5	1	18.5
22	A	A	A	9.3	51.8	10.05	63.1	0.75	11.3
23	A	A	A	13.75	57	13.85	63.8	0.1	6.8
24	A	A	A	12.5	67.6	17.9	88.8	5.4	21.2
25	A	A	A	10.8	73.2	18.55	81.9	7.75	8.7
26	A	A	A	8.05	46.6	9.75	57.7	1.7	11.1
27	A	A	A	11.9	61.4	13.3	68.4	1.4	7
28	A	A	A	10.4	52.6	11.55	57.5	1.15	4.9
29	A	A	A	13.65	70.8	16.9	93.6	3.25	22.8
30	A	A	A	12	78	14.05	95.7	2.05	17.7
31	A	A	A	10.75	59.6	16.95	70.4	6.2	10.8
32	A	A	A	--	71.2	14.25	78.1	--	6.9
33	A	A	A	18.8	85.8	21.55	112.15	2.75	26.35
34	A	A	A	12.7	82	18.35	97.1	5.65	15.1
35	A	A	A	11.9	76	15.5	98	3.6	22
36	A	A	A	18.4	66.8	19.95	84.2	1.55	17.4
37	A	A	A	20.35	83	22.9	121.4	2.55	38.4
38	A	A	A	11.5	84.4	16.75	101.2	5.25	16.8
39	A	A	A	11.4	79	19.45	96.1	8.05	17.1
40	A	A	A	8.05	49.2	10.3	74.2	2.25	25
41	A	A	A	12.7	75.8	14.9	110.2	2.2	34.4
42	A	A	A	11.85	72.4	15.85	93	4	20.6
43	A	A	A	11	62.8	15.35	86.7	4.35	23.9
44	A	A	A	10	59.2	13.6	87	3.6	27.8
45	A	A	A	13.45	54	17.3	79.1	3.85	25.1
46	A	A	A	11.6	57	12.6	71	1	14
47	A	A	A	22.65	70	22.75	95.4	0.1	25.4
48	A	A	A	--	64	14.9	83.4	--	19.4
49	A	A	A	15.9	64.2	17.45	88.7	1.55	24.5
50	A	A	A	9.65	73	17	93.5	7.35	20.5
51	A	A	A	14.35	69.2	17.4	87.4	3.05	18.2
52	A	SNF	A	8.3	49.2	11.4	54	3.1	4.8
53	A	A	A	15	38.2	15.4	55	0.4	16.8
55	A	A	A	9.8	80	15.8	89.7	6	9.7
56	A	A	A	13.45	59.6	14.45	60	1	0.4
57	A	A	A	17.15	92	19.15	102.5	2	10.5
58	A	A	A	13.15	60.3	17.4	98	4.25	37.7
59	A	A	A	13.8	56	14	64.4	0.2	8.4
60	A	A	A	14.8	73	17.15	99.3	2.35	26.3
61	A	A	A	11.15	41.4	12.45	78	1.3	36.6

62	A	A	A	13.4	72	15.5	94.8	2.1	22.8
63	A	A	A	10.75	70.4	14.35	89.7	3.6	19.3
64	A	A	A	10.05	70.8	18.7	95	8.65	24.2
66	A	A	A	12.05	62.4	15.45	83.6	3.4	21.2
68	A	SNF	SNF	14.35	64.4	--	--	--	--
69	A	A	A	11.7	68.4	17.35	86.9	5.65	18.5
70	A	A	A	14	78.8	20.9	105	6.9	26.2
71	A	A	A	8.85	45	12.55	61.8	3.7	16.8
72	A	A	A	9.7	55.4	11.85	75.2	2.15	19.8
74	A	A	A	9.7	62.4	11.2	73.5	1.5	11.1
75	A	A	A	11.6	77	18.5	109.2	6.9	32.2
76	A	A	A	14.55	42.8	15.5	50.7	0.95	7.9
77	A	A	A	15.4	86.4	16.35	101	0.95	14.6
78	A	A	A	7.95	52.2	10.05	61	2.1	8.8
79	A	A	A	13.8	68	16.85	87.6	3.05	19.6
80	A	A	A	9.5	42.4	10.05	62.4	0.55	20
81	A	A	A	14	52	15	65.6	1	13.6
82	A	A	A	13	62.4	14.85	81	1.85	18.6
83	A	SNF	A	10.1	54.6	13.05	64.7	2.95	10.1
84	A	A	A	11.1	57.2	12.65	69.4	1.55	12.2
85	A	A	A	9.85	60	11.7	97.5	1.85	37.5
86	A	A	A	3.8	35	4.2	38.8	0.4	3.8
87	A	A	A	10.3	49.8	13.65	61	3.35	11.2
88	A	A	A	11.5	50.4	14.15	61.4	2.65	11
89	A	A	A	12.45	52	15.5	60.5	3.05	8.5
90	A	A	A	15.25	49.6	15.75	56.6	0.5	7
92	A	A	A	11.7	78.4	18.95	100.4	7.25	22
93	A	A	A	13.85	70.4	16.1	98.4	2.25	28
94	A	A	A	11.6	65.4	16.15	88.3	4.55	22.9
95	A	A	A	8.95	51.8	12.5	67.2	3.55	15.4
96	A	A	A	5.9	59.2	10.7	76.8	4.8	17.6
97	A	A	A	20	82.1	21.7	100.8	1.7	18.7

SURV--Survival
DIAM—Diamteter
HGHT—Height
A—alive
D—dead
NF—tree not found
SNF—site not found (no tree, tag, or flag)

Ash-TerraSorb®

ID#	SRV fall '04	SRV sum '05	SRV fall '05	DIAM (mm) '05	HGHT (cm) '05	DIAM (mm) '06	HGHT (cm) '06	GROWTH DIAM (mm)	GROWTH HGHT (cm)
1	A	A	A	20.75	91.7	23.9	109	3.15	17.3
2	A	A	A	9.75	63	17.95	87.8	8.2	24.8
3	A	A	A	9.95	54	13.55	73.8	3.6	19.8
4	A	A	A	6.3	44.8	8	50	1.7	5.2
5	A	A	A	12.2	65	18.9	97.4	6.7	32.4
6	A	A	A	19.9	109.6	22.95	132.8	3.05	23.2
7	A	A	A	12.9	60.4	13	81.3	0.1	20.9
8	A	A	A	19.9	99.2	26.5	127.2	6.6	28
9	A	A	A	11.65	63.7	13.35	68.6	1.7	4.9
10	A	A	A	19.9	91.2	22.35	121	2.45	29.8
11	A	A	A	9.15	58.2	11.7	70.2	2.55	12
13	A	A	A	6.65	41.8	7.3	56	0.65	14.2
14	A	A	A	5.95	41	7	49.6	1.05	8.6
15	A	A	A	11.7	77	18.3	100.4	6.6	23.4
16	A	A	A	10.25	60.5	13	75.4	2.75	14.9
17	A	A	A	11.25	52.2	13.15	66	1.9	13.8
18	A	A	A	10.9	64.4	12.85	89.4	1.95	25
19	A	A	A	12.35	69.2	14.65	92	2.3	22.8
20	A	A	A	10.95	61	12.6	81.7	1.65	20.7
21	A	A	A	11.2	63.9	15.05	87	3.85	23.1
22	A	A	A	12.35	63	20.95	86	8.6	23
23	A	A	A	18.75	75.2	20.3	131.4	1.55	56.2
24	A	A	A	6.4	48	8.65	65	2.25	17
25	A	A	A	17.05	80.8	22.25	106.2	5.2	25.4
26	A	A	A	9.25	55.4	9.65	67.4	0.4	12
27	A	A	A	15.3	62.5	16	88.4	0.7	25.9
28	A	A	A	11.8	71.2	19.45	96.8	7.65	25.6
29	A	A	A	15.1	58	16.85	93.2	1.75	35.2
30	A	A	A	7.8	41	10.55	57.1	2.75	16.1
31	A	A	A	11.8	54.2	11.85	64.5	0.05	10.3
32	A	A	A	12.35	60.4	16.6	97.5	4.25	37.1
33	A	A	A	12	70.4	15.25	116.2	3.25	45.8
34	A	A	A	15.4	88.6	18.75	120.8	3.35	32.2
35	A	A	A	7.6	61.2	19.85	92.1	12.25	30.9
36	A	A	A	12.55	84.4	17.6	121.6	5.05	37.2
37	A	A	A	10.95	49.8	15.2	93.4	4.25	43.6
39	A	A	A	12.7	64.7	14.15	83.5	1.45	18.8
40	A	A	A	14.65	59.4	15.5	60.8	0.85	1.4
41	A	A	A	12.2	53	14.05	57.3	1.85	4.3
45	A	A	A	8.9	57.4	9.4	82.9	0.5	25.5
46	A	A	A	6.85	41.5	8.4	57.2	1.55	15.7
47	A	A	A	9.2	44.2	13.85	76.6	4.65	32.4
48	A	A	A	14	83.8	16.8	122.4	2.8	38.6
49	A	A	A	8.8	56	12.6	101.7	3.8	45.7
50	A	A	A	18.2	80	20.85	131.1	2.65	51.1
51	A	A	A	7.95	40.2	8.8	76.7	0.85	36.5
52	A	A	A	8.9	39.6	11.7	57.1	2.8	17.5
53	A	A	A	2.95	17.2	4.95	45.8	2	28.6
54	A	A	A	7.75	43.8	10.95	53.8	3.2	10
55	A	A	A	12.7	67	13.7	97.1	1	30.1
57	A	A	A	10.5	55	14.9	83.8	4.4	28.8
58	A	A	A	--	42	8.1	63.4	--	21.4
59	A	A	A	11.4	55.2	14.1	79	2.7	23.8
60	A	A	A	14.4	80.6	16.25	112.3	1.85	31.7
61	A	A	A	9.3	53.4	13.2	66.8	3.9	13.4
63	A	A	A	11	53.7	12.55	66.7	1.55	13
64	A	A	A	8.95	48.4	11.7	67.3	2.75	18.9
65	A	A	A	5.9	33.2	6.65	56.8	0.75	23.6
66	A	A	A	8.3	40	9.85	60.6	1.55	20.6

67	A	A	A	18.6	73.8	21.95	112	3.35	38.2
68	A	A	A	9.35	60.4	12.4	99.4	3.05	39
70	A	A	A	11.45	74.5	13.1	86	1.65	11.5
71	A	A	A	12.2	61.8	15.55	69.5	3.35	7.7
72	A	A	A	8.2	54.7	14.75	95.5	6.55	40.8
73	A	A	A	9.7	82.5	19.5	100.2	9.8	17.7
74	A	A	A	11.25	62.8	13.1	84.5	1.85	21.7
75	A	A	A	17.15	72.7	20	95.7	2.85	23
76	A	A	A	5	27.2	5.5	28.8	0.5	1.6
77	A	A	A	16.85	65.5	18.35	91.4	1.5	25.9
78	A	A	A	13.2	68.6	17.05	89	3.85	20.4
79	A	A	A	--	48	7.1	50	--	2
80	A	A	A	6.95	43.5	8	54.5	1.05	11
81	A	A	A	6.7	42.8	8.65	47.3	1.95	4.5
82	A	A	A	9.95	51.9	10.5	56.8	0.55	4.9
83	A	A	A	13.3	79.8	14.7	98.5	1.4	18.7
84	A	A	A	16.25	69.7	19.2	105.4	2.95	35.7
85	A	A	A	12.35	68.5	12.45	102.2	0.1	33.7
86	A	A	A	9.25	56.9	12.35	63.4	3.1	6.5
87	A	A	A	11.75	77.6	14.05	99.9	2.3	22.3
89	A	A	A	10.9	52.2	14.45	71.4	3.55	19.2
90	A	A	A	10.2	68.2	12.35	99.2	2.15	31
91	A	A	A	8	42.4	10.2	58.8	2.2	16.4
92	A	A	A	15.85	58.8	20.65	99.5	4.8	40.7
93	A	A	A	8.2	51.4	8.85	58	0.65	6.6
95	A	A	A	6.15	38.8	9.3	49.2	3.15	10.4
96	A	A	A	7.1	54	7.5	58.8	0.4	4.8
98	A	A	A	9.85	55.6	12.6	68.2	2.75	12.6
A	A	D	D	14.6	56	--	--	--	--

SURV--Survival
DIAM—Diamteter
HGHT—Height
A—alive
D—dead
NF—tree not found
SNF—site not found (no tree, tag, or flag)

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